

# Atlantic Richfield Company

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December 31, 2013

Mr. Steven Way  
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**RE: Evaluation of Source Water Controls Report  
Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01  
Dolores County, Colorado**

Dear Mr. Way:

On behalf of Atlantic Richfield Company (Atlantic Richfield), please find enclosed the *Evaluation of Source Water Controls Report* (report) prepared for the Rico-Argentine Mine Site (site). This report was performed pursuant to the requirements in Task E – Source Water Investigation and Controls / Subtask E3 – Evaluation of Hydraulic Controls Alternatives accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, United States Environmental Protection Agency, Region 8, (U.S. EPA), dated March 9, 2011 (Docket No. CERCLA-08-2011-0005).

This report evaluates potential methods for decreasing contaminant discharge from the St. Louis Tunnel by controlling mine water flow rates and/or concentrations. Available flow and chemical concentration data were reviewed for the sources that contribute to the St. Louis Tunnel discharge, including the Blaine Tunnel, Southeast Cross-cut, and Northwest Cross-cut. Potential hydraulic control methods to reduce or eliminate flows were evaluated, and the results of the 2012 and 2013 alkaline solution injection tests were summarized and evaluated. Complete results of the 2012 and 2013 St. Louis Tunnel Discharge Source Mine Water Treatability Studies will be presented in a forthcoming completion report that will be submitted to the U.S. EPA by March 31, 2014.

If you have any questions regarding this report, please feel free to contact me at (714) 228-6770 or via e-mail at [Anthony.Brown@bp.com](mailto:Anthony.Brown@bp.com).

Sincerely,



Tony Brown  
Project Manager Mining  
Atlantic Richfield Company

Enclosure: *Evaluation of Source Water Controls Report*



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**EVALUATION OF SOURCE WATER CONTROLS  
Rico-Argentine Mine Site – Rico Tunnels  
Operable Unit OU01  
Dolores County, Colorado**

*Prepared for:*  
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December 2013

Project No. SA11161313

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## LIST OF ACRONYMS

AMEC	AMEC Environment & Infrastructure, Inc.
Atlantic Richfield	Atlantic Richfield Company
C	concentration
CaCO <sub>3</sub>	calcium carbonate
CDRMS	Colorado Division of Reclamation, Mining and Safety
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cfs	cubic feet per second
DR-3	St. Louis Tunnel discharge monitoring location
DR-3A	St. Louis Tunnel discharge injection test sampling location
DR-6	St. Louis Ponds effluent sampling location
DR-G	Dolores River Gaging Station
ft/hr	feet per hour
gpm	gallons per minute
HRT	hydraulic residence time
IBF	in-by flume
K <sub>2</sub> CO <sub>3</sub>	potassium carbonate
lbs/day	pounds per day
mg/L	milligram per liter
mV	millivolts
NaOH	sodium hydroxide
NE	northeast
NPDES	National Pollutant Discharge Elimination System
NW	northwest
OBF	out-by flume
ORP	oxidation reduction potential
Q	flow rate
RAWP	Removal Action Work Plan
report	Evaluation of Source Water Controls Report
SE	southeast
site	Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01
U.S. EPA	United States Environmental Protection Agency
UAO	Unilateral Administrative Order
µg/L	micrograms per liter
%	percent

## EXECUTIVE SUMMARY

This *Evaluation of Source Water Controls Report* (report) summarizes the available information on the sources of water and contaminants that discharge from the St. Louis Tunnel at the Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, in Dolores County, Colorado (site). Potential methods for reducing contaminant loading by controlling mine water flow rates and/or concentrations are evaluated.

The St. Louis Tunnel discharge originates as precipitation that infiltrates into the subsurface and migrates along fractures and faults. Water collects in the mine workings, may react with mineralized materials, and drains to the St. Louis Tunnel. The primary mine workings contributing to drainage from the St. Louis Tunnel are the Northwest (NW) Cross-cut (12% to 25% of the flow), the Southeast (SE) Cross-cut (39% to 82% of the flow), and the 145 Raise (less than 10% of the flow), though groundwater infiltration into the St. Louis Tunnel (downgradient of the cross-cuts) may contribute a substantial part of the discharge. Available analytical data indicates that the NW Cross-cut contributes the majority of zinc, cadmium, and manganese.

Based on currently available information, there are no readily accessible locations to install bulkheads or plugs for hydraulic control of mine water. Control measures in the accessible part of the Blaine Tunnel would not reduce the hydraulic loading at the St. Louis Tunnel significantly. Although the existence of major faults is known and infiltration through these features is presumed to occur, evaluation of their accessibility for grouting, their distribution and extent, and the extent to which grouting would reduce water flow to the St. Louis Tunnel was beyond the scope of this investigation.

Injection of alkaline solutions into the 517 Shaft during 2012 and 2013 reduced concentrations in the shaft to near zero concentrations and decreased concentrations of zinc, cadmium, manganese, and other metals at the St. Louis Tunnel discharge. Total alkalinity and pH increased and metals concentrations decreased in the 517 Shaft. Metals concentrations at the St. Louis Tunnel discharge were decreased by up to 40% during the 2012 injection of potassium carbonate and by as much as 26% during the 2013 injection of sodium hydroxide. The contaminant load from the SE Cross-cut was treated during both injection tests, and the contaminant load from the NW Cross-cut was partially treated during the 2012 test.

No further testing of in-situ chemical treatment is recommended at this time. If the other water treatment alternatives that currently are being evaluated for the site do not provide sufficient treatment for the St. Louis Tunnel discharge, in-situ chemical precipitation could be revisited. Future development of this treatment method could focus on identifying a better injection location and improving chemical delivery methods.

## **EVALUATION OF SOURCE WATER CONTROLS**

### **Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01**

### **Dolores County, Colorado**

#### **1.0 INTRODUCTION**

This *Evaluation of Source Water Controls Report* (report) has been prepared by AMEC Environment & Infrastructure, Inc. (AMEC), on behalf of Atlantic Richfield Company (Atlantic Richfield), to describe recent efforts to understand and evaluate the sources of water and contaminants that discharge from the St. Louis Tunnel portal at the Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01 (site). The site is located in the San Juan Mountains of southwestern Colorado, just north of the Town of Rico in Dolores County, Colorado (Figures 1-1 and 1-2). The site consists of the St. Louis Tunnel and associated complex of underground mine workings and a series of settling ponds (Figures 1 through 4 of Attachment 1).

In 2011, the United States Environmental Protection Agency (U.S. EPA) issued a *Unilateral Administrative Order for Removal Action (UAO), Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Docket No. 08-20011-0005* (U.S. EPA, 2011a). The UAO requires Atlantic Richfield “to conduct removal actions ... to abate an imminent and substantial endangerment to the public health or welfare or the environment that may be presented by the actual or threatened release of hazardous substances at or from the Site.”

The UAO includes the Removal Action Work Plan (RAWP; U.S. EPA, 2011b), which describes specific investigations and removal action tasks to be completed for the site. Task E of the RAWP requires that Atlantic Richfield evaluate the sources of water that enter the mine workings and discharge at the St. Louis Tunnel and evaluate potential control methods for reducing or eliminating flows that contribute to the discharge. This report has been prepared to fulfill the reporting requirements of Subtask E3, “Evaluation of Hydraulic Controls Alternatives.” This subtask includes an evaluation of methods to reduce flows into and/or contamination of water flowing through the mine workings.

#### **1.1 OVERVIEW AND OBJECTIVES**

The main objectives of this report are to summarize the available investigation data on the sources of water and contaminants that discharge from the St. Louis Tunnel and to evaluate potential methods for controlling the flow of water and/or the discharge of contaminants. This report presents the current understanding of the sources of water and contaminants and evaluates potential methods for reducing contaminant loading by controlling flow rates and/or

concentrations that discharge from the St. Louis Tunnel. Specifically, this report includes information on the following:

- Layout of the mine workings, sources of water and contaminants within the mine workings, and flow rates and contaminant concentrations at the St. Louis Tunnel discharge (Section 2);
- An evaluation of methods to reduce or control St. Louis Tunnel discharge flows (Section 3);
- An overview of the injection testing that was conducted in 2012 and 2013 to evaluate in-situ chemical precipitation to reduce contaminant concentrations in the St. Louis Tunnel discharge (Section 4); and
- Conclusions and recommendations based on currently available information (Section 5).

## **2.0 SOURCE WATER CHARACTERIZATION**

This section briefly describes the mine workings that are connected to the St. Louis Tunnel. The current understanding of the interconnected mine workings and the sources of water and metals that discharge from the St. Louis Tunnel are described.

### **2.1 ST. LOUIS TUNNEL AND RICO-ARGENTINE MINE WORKINGS**

The original portal of the St. Louis Tunnel was located at the western base of Telescope Mountain above the relatively flat Dolores River valley (Figure 1-1). The average elevation of the valley (as significantly modified by previous mining and minerals processing activities) is about 8,800 feet above mean sea level. The St. Louis Tunnel drains historical mine workings that extend into Telescope Mountain to the north and Dolores Mountain to the southeast. The interconnected mine workings have been partially mapped by AECOM, based on historic surveys of mine workings (Attachment 1). Mine water that continuously discharges from the St. Louis Tunnel flows through a series of settling ponds before discharging to the Dolores River at monitoring location DR-6, approximately 0.2 mile upstream of the bridge at Colorado State Highway 145, north of the Town of Rico (Figures 1-1 and 1-2).

The St. Louis Tunnel was originally driven through about 330 feet of colluvium at the base of CHC Hill and then continued into the bedrock of the Hermosa Formation (AECOM, 2013a). Much of the colluvium over the tunnel was subsequently excavated; part of the colluvial section of the tunnel is collapsed and partially plugged with displaced colluvium and damaged timber supports. This debris plug impounds water in the St. Louis Tunnel in a pool that has an

estimated volume of 670,000 gallons under average flow conditions, although the extent and volume of the pool varies with the inflow from the mine workings (AECOM, 2013b).

The St. Louis Tunnel extends about 4,600 feet northeast into Telescope Mountain, where it intersects the northwest (NW) and southeast (SE) cross-cuts (Figure 1-2). The St. Louis Tunnel continues to the northeast about 500 feet beyond the intersection with these cross-cuts as the 145 Raise. The NW Cross-cut connects the St. Louis Tunnel with the Mountain Spring Mine and other mines in what is referred to herein as the Mountain Springs-Wellington workings, which are generally to the north within Telescope Mountain (URS, 2012).

The SE Cross-cut is approximately 4,400 feet long and connects the St. Louis Tunnel to the extensive interconnected Rico-Argentine Mine workings at the 500 level in the southeastern portion of the site in the vicinity of Silver Creek and Dolores Mountain (Figure 3 of Attachment 1; URS, 2012). For nearly 1,060 feet of its length, the SE Cross-cut is located within or adjacent to the Blackhawk Fault. The workings in the southeastern portion of the site include the Argentine, Blaine (100 level; see Section 2.4), and several levels both above and below the Blaine Tunnel. There are at least five levels below the Blaine Tunnel: the 200, 300, 400, 500 (also referred to as the St. Louis level), 600, and 700 levels. Workings above the Blaine level include the Rico Consolidated middle and upper tunnels, the Argentine Tunnel, the Log Cabin (Blackhawk) Tunnel, and several tunnels above the Log Cabin portal (including the Blacksmith Tunnel). Several of these workings have reportedly collapsed at the portals and have not been accessed recently, with the exception of the Argentine Tunnel (URS, 2012).

At least three vertical shafts are connected to the SE Cross-cut (Figure 3 of Attachment 1). The 517 Shaft is connected to the SE Cross-cut by a short drift at the 500 level; this shaft also connects to four levels of mine workings above the 500 level (the 400, 300, 200, and 100 levels) and two deeper levels (the 600 and 700 levels; Figure 4 of Attachment 1). The Argentine Shaft is located near the 517 Shaft and is also north of Silver Creek (Figure 4 of Attachment 1). This shaft is connected to workings at the 200 and 300 levels and is believed to bottom at the 300 level (URS, 2012). The Number 3 Shaft is located at the Blaine Tunnel level about 1,000 feet inside the Blaine Tunnel from the portal. The top of this shaft is at the Blaine Tunnel (100) level, and it extends down to at least the 300 level. Of these three shafts, only the top of 517 Shaft is considered safely accessible. The top of the 517 Shaft was recently accessed for the 2012-2013 injection testing (Section 4), but the Argentine and Number 3 Shafts have not been inspected recently due to a lack of safe access. During the 2012 investigation activities, the inside of the J-vent above the Argentine Shaft was found to be blocked by debris at the ground surface; thus, the Argentine Shaft could not be inspected. The top of the Number 3 Shaft is located within an inaccessible part of the Blaine Tunnel. In addition to the vertical shafts, there

are other mine workings (including raises, declines, inclines, winzes, and stopes) that locally interconnect the various levels of the mine workings.

## **2.2 ST. LOUIS TUNNEL DISCHARGE RATES AND WATER SOURCES**

Water that discharges from the St. Louis Tunnel portal originates as precipitation that infiltrates into the subsurface. Although the locations of infiltration to the subsurface have not been well characterized or quantified, much of the infiltration is thought to occur through fractures and faults (e.g., Blackhawk Fault, Princeton Fault, and Last Chance Fault). Some of the infiltration flows into the mine workings and drains through the SE and NW Cross-cuts to the St. Louis Tunnel, while part of the infiltration is stored as groundwater that may eventually flow into the mine workings and ultimately discharge from the St. Louis Tunnel. The relatively consistent isotopic composition of water that discharged from the St. Louis Tunnel between May and October 2011 suggests that this water results from a consistent inflow of groundwater to the mine workings (URS, 2012). The relatively constant base flow of well-mixed, clean groundwater (i.e., groundwater with moderate pH and low concentrations of metals) is apparently augmented by more contaminated flows that infiltrate into the mine workings during spring runoff (URS, 2012).

Some of the water that discharges from the St. Louis Tunnel portal may originate from Silver Creek. URS (2012) found that Silver Creek loses some water in the vicinity of the Blackhawk Fault, probably due to infiltration to faults and fractures. This water may eventually drain to the St. Louis Tunnel and comprise a portion of the discharge, although tracers that were added to Silver Creek were not detectable in the St. Louis Tunnel discharge while monitoring was being conducted. The contribution of Silver Creek to the overall St. Louis Tunnel discharge therefore could not be estimated (URS, 2012).

Water that flows into the mine workings drains downward through the interconnected series of shafts, raises, winzes, declines, inclines, and stopes. Water that is not stored in deep shafts (such as the 517 Shaft) or that does not exit the mine workings through faults and fractures as groundwater eventually flows to the NW Cross-cut, SE Cross-cut, and 145 Raise (Figure 1 in Attachment 1), which are the primary contributors to drainage from the St. Louis Tunnel. Tracer tests conducted in 2011 confirmed that the 517 Shaft in the southeastern portion of the site is hydraulically connected to the St. Louis Tunnel discharge via the SE Cross-cut (URS, 2012). Although no recent confirmation is available, flow data from Anaconda (1982) and historic mine maps indicate that some portions of the mine workings north of the St. Louis Tunnel in Telescope Mountain are hydraulically connected to the St. Louis Tunnel via the NW Cross-cut.



Flow observations made from inside the St. Louis Tunnel during August 1980 (Table 2-1; Attachment 2) were reported by Anaconda (1982). These observations indicate that the NW Cross-cut contributed an estimated 25 percent (%) of the flow, the SE Cross-cut contributed about 67% of the flow, and the 145 Raise contributed about 8% of the flow that discharges from the St. Louis Tunnel portal (Anaconda, 1982). It is assumed that these observations were made at the intersection of the St. Louis Tunnel with the other cross-cuts; additional flow may enter as groundwater collected between this location and the St. Louis Tunnel adit<sup>1</sup> (Figure 1 of Attachment 1). Since the St. Louis Tunnel cannot be accessed currently, volumetric contributions to the St. Louis Tunnel discharge have not been measured recently, and there are no recent observations to confirm that the flow proportions reported by Anaconda (1982) are still accurate. Flow proportions are presumed to vary seasonally, given the seasonal flow variations at DR-3 and the inferred primary precipitation infiltration source of the flows.

St. Louis Tunnel discharge measurements are available sporadically between 1973 and 2010 and almost continuously since May 2011. In September 1973, the discharge was approximately 1,400 gallons per minute (gpm; 3.1 cubic feet per second [cfs]). Additional historic flow data is available between July 1979 and May 1983 (Figure 2-1), June 2000 and January 2006 (Figure 2-2), and December 2010 and October 2013 (Figure 2-3). Flow rates in May and August 1995 were estimated to be 990 gpm (2.2 cfs) and 2,200 gpm (4.9 cfs), respectively; the latter estimate is the highest reported St. Louis Tunnel discharge flow rate. The minimum recorded St. Louis Tunnel discharge flow rate is 260 gpm (0.59 cfs) in July 2004. Recently, flow rates at the St. Louis Tunnel portal between May 2011 and October 2013, as measured by converting stage measurements from an ultrasonic level sensor and a submerged pressure transducer installed at the DR-3 flume, ranged from 480 gpm to 910 gpm (1.1 cfs and 2.0 cfs, respectively) and averaged 650 gpm (1.5 cfs).

In 2013, the St. Louis Tunnel discharge (as measured at DR-3) appeared to be stable, with water levels through the flume varying by less than 0.12 inch for months at a time, corresponding to flow rates of 498 gpm to 574 gpm. The cause of this stabilization is unknown, but the lack of seasonal variation may indicate instrument error. Manual flow measurements were performed throughout the summer of 2013 and indicated that flow rates varied from 426 gpm to 570 gpm (Figure 2-3).

Dolores River flow rates have been recorded at a United States Geological Survey (USGS) gauging station (USGS site number 09165000; monitoring location DR-G), located

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<sup>1</sup> Undated geologic mapping of the main St. Louis Tunnel believed to have been prepared in the mid- to late-1950s identified minor seepage in a few locations. Based on the detail and nature of the mapping, it is believed that the existence of major groundwater inflows would have been noted in the mapping.



approximately 5 miles downstream (south) of DR-6 (Figure 1-1), since 1951. Flow rates in the Dolores River at DR-G vary seasonally, with annual peak flow rates typically occurring in May and June as a result of snowmelt runoff. Flow rates of mine water discharges, as measured at the St. Louis Tunnel (DR-3), also vary seasonally, with generally higher flows during the summer, following the spring snow melt runoff period, and lower flows during the fall, winter, and spring. The peak flow rate from the St. Louis Tunnel (as measured at DR-3) lags behind the peak flow rate in the Dolores River (DR-G; Figures 2-1, 2-2, and 2-3). Dolores River peak flow rates generally occur rapidly over a period of two to four weeks. In contrast, DR-3 flow rates appear to increase gradually with the advent of spring runoff, reach their peak five to ten weeks after peak flow in the Dolores River, and remain high over longer periods of time than the Dolores River (nearly two months). Additionally, peak DR-3 flow rate magnitudes generally correlate to peak DR-G flow rates magnitudes; in years with higher peak flow rates measured at DR-G, higher peak flow rates also are measured at DR-3.

These flow rate trends indicate that the St. Louis Tunnel discharge likely is impacted, if not largely controlled, by infiltration of snowmelt into groundwater. In years with greater winter precipitation<sup>2</sup> and/or higher snowmelt runoff, as measured at DR-G, higher flow rates may be anticipated at DR-3 (Figures 2-2 and 2-3). St. Louis Tunnel discharge rates may be predictable based on Dolores River flow trends, as described in Section 5 of AECOM (2013b).

### **2.3 ST. LOUIS TUNNEL CONTAMINANT DISCHARGE AND CONTRIBUTIONS**

Mine water that discharges from the St. Louis Tunnel has elevated concentrations of several metals, notably cadmium, manganese, and zinc. As with the flow contributions from the NW Cross-cut, SE Cross-cut, and 145 Raise, there is no specific, recent information on the contributions of metal loadings from each of these sources. However, the Anaconda (1982) memorandum included analytical data for several analytes (Table 2-1), allowing an estimation of mass loading contributions from the three sources that drain into the St. Louis Tunnel. The reported zinc concentrations ranged from 0.50 milligram per liter (mg/L) from the 145 Raise to 27 mg/L in the NW Cross-cut (Table 2-1). Based on the reported flow proportions and concentrations, the NW Cross-cut contributes 4.5 times more cadmium, 3.9 times more zinc, and 10 times more iron load than the SE Cross-cut, whereas the SE Cross-cut contributes 1.3 times as much sulfate load as the NW Cross-cut. The 145 Raise is a minor contributor to both flow and contaminant load.

<sup>2</sup> Annual cumulative precipitation data was obtained from the Scotch Creek SNOTEL site (NRCS, 2013), located approximately four miles south of the site. Annual cumulative precipitation is reported by water year beginning annually on October 1. Precipitation data for the Scotch Creek SNOTEL site is available from October 1985 to present.

When the zinc concentrations reported by Anaconda (1982) are combined with the estimated flow proportions (25% from the NW Cross-cut, 67% from the SE Cross-cut, and 8% from the 145 Raise) to calculate mass loading rates (mass per day) from each source, the mass balance does not converge (i.e., the sum of the zinc mass loading contributed by the three sources does not equal the zinc mass exiting the St. Louis Tunnel).

$$Q_{NW}C_{NW} + Q_{SE}C_{SE} + Q_{145}C_{145} = Q_{SLT}C_{SLT}$$

where each Q is a flow rate and each C is a concentration. The subscripts refer to the different sampling locations: NW refers to the NW Cross-cut; SE refers to the SE Cross-cut; 145 refers to the 145 Raise; and SLT refers to the St. Louis Tunnel.

$$\frac{1}{4}Q_{SLT}(27 \text{ mg/L}) + \frac{2}{3}Q_{SLT}(2.62 \text{ mg/L}) + \frac{1}{12}Q_{SLT}(0.50 \text{ mg/L}) = Q_{SLT}(5.2 \text{ mg/L})$$

Dividing by  $Q_{SLT}$  yields:

$$6.75 + 1.75 + 0.04 \neq 5.2$$

Mass balance calculations with other analytes (including fluoride, which is likely to be conservative) result in similar discrepancies. There are several possibilities for the inequality of this mass balance calculation. The reported analytical results could be inaccurate; the analytes may not have been conservative due to precipitation, co-precipitation, or sorption within the St. Louis Tunnel or during sample transport;<sup>3</sup> or the estimated flow proportions or total flow may have been inaccurate. The flow proportions are reported as “Estimated portion of flow” (Anaconda, 1982), and the location and methods for these estimates are uncertain. The flows were apparently not measured, which may have resulted in substantial errors in the estimated relative flow contributions from each source. The contributing flows also may have been diluted by relatively clean inflow to the St. Louis Tunnel between the intersection and the portal, although historical information does not indicate substantial inflow to the St. Louis Tunnel. The possible inaccuracies in the reported flow estimates are discussed in the following paragraphs.

Assuming that the estimated flow proportions reported by Anaconda (1982) are inaccurate, the flow and mass balances converge. It is not unreasonable, based on available information, to assume that the flow and contaminant mass contributions from the NW Cross-cut, SE Cross-cut, and 145 Raise contribute essentially all of the flow and contaminant mass that discharges from the St. Louis Tunnel. Thus, the flow and mass balances should both converge (i.e., inputs at the tunnel intersection with the three sources should equal outputs at DR-3). In an effort to

<sup>3</sup> According to the historical documents in Attachment 2, samples were taken on August 18, 1980, and received by the lab on August 25, 1980.

force the mass balance to converge, the Solver function in Microsoft Excel was used to vary the contributing flow proportions to minimize the discrepancies in the mass balances (Table 2-2). Under this scenario, the NW Cross-cut contributes only 12% of the flow (as compared to the reported approximately 25%) but the majority of the zinc, cadmium, and iron. The SE Cross-cut contributes 82% (versus the reported 67%) of the flow and most of the sulfate. The 145 Raise contributes less than 10% (consistent with the reported estimate of about 8%) of the flow and mass for all constituents considered. Results of this least squares optimization procedure are summarized in Table 2-2.

An additional possibility is that the flow proportions reported by Anaconda (1982) do not account for inflow between the tunnel intersection and the St. Louis Tunnel portal. If the flow proportions were estimated at the intersection of tunnels, inflow to the St. Louis Tunnel from fractures or drill holes (Anaconda, 1985) between the intersection and the portal (a distance of about 4,400 feet) were not included. Assuming that contaminant concentrations in any St. Louis Tunnel groundwater inflow are relatively low, the concentrations emerging from the St. Louis Tunnel would be diluted relative to the expected concentrations at the tunnel confluence.

Based on these flow assumptions and an assumption that the zinc concentration in the St. Louis Tunnel inflow between the tunnel intersection and the portal is relatively low (0.5 mg/L, equal to the concentration in the flow from the 145 Raise), mass balances on the analytes listed in Table 2-1 indicate that inflow to the St. Louis Tunnel may contribute as much as 40% of the flow that discharges from the portal. Under this scenario, zinc that discharges from the St. Louis Tunnel portal is primarily from the NW Cross-cut (76% of the zinc mass, 15% of the DR-3 flow), with lower mass contributions from the SE Cross-cut (20% of the zinc mass, 39% of the DR-3 flow), the 145 Raise (less than 1% of the zinc mass, 5% of the DR-3 flow), and the St. Louis Tunnel inflow (4% of the zinc mass, 42% of the DR-3 flow).

Although the flow and mass contributions cannot be verified due to lack of access for sampling and flow measurement and the mass balances do not account for possible losses of metals within the mine workings, these results suggest that the NW Cross-cut contributes a substantial fraction of the contaminant mass that discharges from the St. Louis Tunnel, while the SE Cross-cut apparently contributes most of the flow.

## 2.4 BLAINE TUNNEL SOURCE AREA

The Blaine Tunnel was originally thought to be a major contributor of mine water and contaminants that discharge from the St. Louis Tunnel portal. This section describes historical information, recent rehabilitation work, and the results of recent investigations at the Blaine Tunnel. As described below and summarized in Section 2.4.7, it appears that the Blaine Tunnel

portal area may not be a major contributor to the loads of the primary metals of interest (i.e., zinc, cadmium, and manganese) in the St. Louis Tunnel discharge.

#### **2.4.1 Blaine Tunnel Description**

The Blaine Tunnel portal is located south of Silver Creek (Figure 3 of Attachment 1). The tunnel (at the 100 level) extends about 3,750 feet southeast into Blackhawk Mountain, with workings that span about 1,300 feet north to south and 2,300 feet east to west (Burack, 1982). Several faults intersect the tunnel, including the Blackhawk fault, Last Chance fault, and numerous minor faults and localized fractures (Burack, 1982). These faults and fractures may provide flow paths for infiltration into the Blaine Tunnel and/or the lower mine workings (200, 300, 400, and 500 [St. Louis/SE Cross-cut] levels). The Blaine Tunnel also intersects at least one vertical shaft, the Number 3 Shaft, which likely provides a vertical flow path to at least the lower 200 and 300 levels. The Humboldt Drift branches east off of the Blaine Tunnel approximately 470 feet from the portal and then connects to the Morris-Cook Incline, providing a flow path for water from the Blaine Tunnel directly to the lower levels. Other interconnected drifts, inclines, and stopes potentially provide additional flow paths to the lower mine workings and the SE Cross-cut (Attachment 1).

#### **2.4.2 Blaine Tunnel Historical Discharges**

Water historically drained from the Blaine Tunnel and discharged directly to Silver Creek through the 100-level portal. The Blaine Tunnel was one of two permitted discharges at the Rico-Argentine Mine (National Pollutant Discharge Elimination System [NPDES] Permit CO-0029793, outfall 001). In the mid- to late-1970s, mine water in the Blaine Tunnel was diverted underground to the St. Louis Tunnel and subsequently discharged at the St. Louis Tunnel portal, resulting in zero discharge from the Blaine Tunnel (Jahnke, 1977). A concrete cofferdam was installed in 1990 approximately 350 feet inside the Blaine Tunnel from the portal, eliminating direct discharge of mine water from the Blaine Tunnel to Silver Creek (Grayling Environmental, 2006). The concrete cofferdam currently diverts water to the Humboldt Drift and subsequently the Morris-Cook Incline, where it flows downward through interior mine workings to the SE Cross-cut and eventually the St. Louis Tunnel.

#### **2.4.3 2011 Blaine Tunnel Activities**

In 2011, the U.S. EPA investigated the Blaine Tunnel as one of the source areas for water and contaminants discharging from the St. Louis Tunnel (URS, 2012). The Blaine Tunnel portal was in poor condition, and leaks in the cofferdam allowed drainage to flow toward the portal. Water entering the Blaine Tunnel via multiple seeps and raises pooled behind the cofferdam, and a blockage restricted flow to the Humboldt Drift, thereby inhibiting drainage from the Blaine Tunnel

to lower levels. Rehabilitation work was conducted to raise and reinforce the cofferdam and to reinforce the portal to allow safe entry. The tunnel was explored to a distance of about 150 feet beyond the cofferdam; conditions were determined to be unsafe for entry beyond this point (URS, 2012).

Pooled water behind the cofferdam had a pH between 2.0 and 2.5 (URS, 2012). Water samples were collected from the pool in August and October 2011 for analysis of total and dissolved metals, sulfate, and isotopes, but the flow rate to the Humboldt Drift was not quantified. The sample collected in October generally had higher metals concentrations than the sample collected in August. Complete analytical results for Blaine samples are provided in Table 4 of URS (2012). Highlights of the analytical results for the October 2011 sample are as follows:

- Total and dissolved cadmium were detected at concentrations of 953 micrograms per liter (µg/L) and 967 µg/L, respectively.
- Total and dissolved manganese were detected at concentrations of 61,500 µg/L and 61,600 µg/L, respectively.
- Total and dissolved zinc were both detected at 161,000 µg/L.
- Total and dissolved iron were detected at concentrations of 1,390,000 µg/L and 1,420,000 µg/L, respectively.

For each of these metals, the reported total and dissolved concentrations are practically equal, within the limits of analytical precision, indicating that the metals in these samples were present in the dissolved form, as expected in the pH range of 2 to 2.5.

Water flowing into the Blaine Tunnel from a raise located in-by<sup>4</sup> the cofferdam and Humboldt Drift ("flowing raise") was sampled and also had elevated metals concentrations, with concentrations that were similar to or somewhat higher than concentrations in the October 2011 cofferdam pool sample. Water was observed to be flowing into the Blaine Tunnel from the flowing raise at approximately 5 gpm to 10 gpm (URS, 2012). Metals concentrations detected in the Blaine samples were lower than in a sample collected from the Argentine Tunnel (see Section 2.5.1).

A tracer study using fluoride confirmed the hydraulic connection between the Blaine Tunnel and the 517 Shaft (URS, 2012). Fluoride injected into the mine water pooled behind the cofferdam was first detected in the 517 Shaft after approximately 10 hours, while the fluoride peak arrived

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<sup>4</sup> The in-by location denotes a location that is farther into the mine, compared to the cofferdam and Humboldt Drift locations.

after about 68 hours. Assuming a flow distance of 660 feet, the average velocity of the advection front was about 66 feet per hour (ft/hr), and the velocity of the fluoride peak was about 9.7 ft/hr.

URS (2012) concluded that the Blaine Tunnel is one source of contaminated water to the St. Louis Tunnel. Additional work was recommended to (1) stabilize the Blaine Tunnel cofferdam to prevent surface migration to Silver Creek; (2) remove blockages to allow water from the Blaine Tunnel to flow to the St. Louis Tunnel; (3) install equipment to measure flow rates within the Blaine Tunnel; and (4) perform additional sampling within the Blaine Tunnel to characterize seasonal variations in water quality.

#### **2.4.4 2012-2013 Blaine Tunnel Rehabilitation Work**

Rehabilitation work was conducted in the Blaine Tunnel in 2012 and 2013 to stabilize and restore portions of the underground workings, allow mine water to continue to drain to the lower workings and ultimately to the St. Louis Tunnel, and allow further hydrologic characterization of the accessible Blaine workings. The first phase of rehabilitation work was conducted in August and September 2012, and a second phase was completed in August and September 2013. Rehabilitation work was completed and reported by Shannon and Wilson, Inc. (2012, 2013).

During 2012 rehabilitation activities, the U.S. EPA and Colorado Division of Reclamation, Mining and Safety (CDRMS) contractors reconstructed the Blaine Tunnel portal, cleared obstructions to improve access, and added reinforcing along parts of the tunnel. The pool impounded by the Blaine Tunnel cofferdam was dewatered by pumping and discharging more than 14,000 gallons of water to the 517 Shaft. Rehabilitation activities during the 2013 field season focused on the Humboldt Drift and included clearing collapsed areas, installing timber sets to reinforce the walls and roof, and excavating a drainage trench along the floor to encourage mine water to flow down the Humboldt Drift toward the Morris-Cook Incline and presumably to lower levels of the mine workings. During 2013 rehabilitation activities, pooled water was pumped from the Blaine Tunnel to the 517 Shaft, but the pumped volume was not recorded.

#### **2.4.5 Blaine Flow Characterization**

Between September 23 and 25, 2012, after dewatering the pool behind the Blaine Tunnel cofferdam, personnel from the CDRMS and URS Operating Services constructed a sandbag berm in the Blaine Tunnel, in-by the cofferdam and Humboldt Drift (Figure 2-4). To quantify the flow of mine water and contaminant loading from the Blaine Tunnel down the Humboldt Drift and the Morris-Cook Incline, a flume (Attachment 3-1) and solar-powered Hach Sigma 950 flow meter with an ultrasonic depth sensor (Attachment 3-2) were installed within the sandbag berm in October 2012. The flume was gauged to measure water depths and corresponding flow rates



as low as approximately 0.1 gpm. The ultrasonic sensor was installed directly above the flume (Attachment 3-3) for measuring water depths. A data logger was installed outside the Blaine Tunnel to record ultrasonic depth measurements without the need for in-tunnel personnel.

The sandbag berm was constructed at a natural high-point in the Blaine Tunnel floor to capture influent from the “flowing raise” located in-by the Humboldt Drift (Figure 2-4 and Picture 4 of Attachment 3-3). Despite having constructed the sandbag berm out-by (downgradient of) the “flowing raise,” additional influent to the Blaine Tunnel was observed during periodic Blaine Tunnel inspections near the vertical timbers in-by the Humboldt Drift (labeled as “inflow” in Figure 2-4 and Picture 1 of Attachment 3-3). This inflow was located out-by the flume and therefore not quantified in flume flow measurements. In addition to this inflow, other influent likely contributes to Humboldt Drift flows; many small drips and seeps within the accessible reaches of the Blaine Tunnel have been reported by in-tunnel personnel. Humboldt Drift flows may be augmented by influent from various other levels of the mine workings, and flow paths other than the Humboldt Drift may connect Blaine out-by the flume (OBF)<sup>5</sup> water to the St. Louis Tunnel discharge. CDRMS observed that water appeared to flow into the workings from behind the Blaine Tunnel flume, suggesting that there may be routes other than the Humboldt Drift for Blaine Tunnel water to flow to the 517 Shaft and SE Cross-cut.<sup>6</sup>

Flow through the flume was first detected on November 25, 2012 (Figure 2-5), indicating that the pool in-by the sandbag berm had re-filled with water after dewatering during rehabilitation and berm construction (Section 2.4.4). Flow rates increased to a maximum of approximately 3.0 gpm on January 18, 2013. Flow rates then decreased throughout February, remained low during March and April, and increased between June and September. The flow rate reached a maximum of 2.8 gpm on September 21, 2013 (Figure 2-5), and decreased thereafter. It is uncertain if the increased flow rates were caused by Blaine Tunnel rehabilitation activities (i.e., dewatering within the Blaine Tunnel) or if these flow rate trends indicate a several month lag between snowmelt in May and June and flow through the Blaine Tunnel, similar to the lag shown in Figure 2-3 and discussed in Section 2.2. Additional water level measurements throughout winter 2013/2014 will help determine if the peak flow rates observed in January 2013 were typical for the Blaine Tunnel or the lingering effect of rehabilitation activities.

#### **2.4.6 Blaine Contaminant Characterization**

Water samples were collected from the Blaine Tunnel during 2012 and 2013 to further characterize contaminant concentrations. Analytical results and field parameters are provided in

<sup>5</sup> The OBF location is out of the mine (downgradient), compared to the flume location.

<sup>6</sup> The Number 3 Shaft, located in-by the Blaine Tunnel flume, is a possible alternative vertical flow path to the SE Cross-cut.

Table 2-3, and photo documentation of Blaine Tunnel activities is provided in Attachment 3-3. A baseline water sample was collected in-by the cofferdam on September 5, 2012. Later samples were collected after flume construction from flowing water OBF and pooled water in-by the flume (IBF).<sup>7</sup>

Blaine samples collected in 2012 and 2013 generally had low pH, high oxidation reduction potential (ORP), high concentrations of metals and sulfate, and non-detectable alkalinity. In-by flume and OBF results were generally similar. The pH of the samples ranged from 2.0 to 2.6, and the pH of the OBF sample was typically somewhat lower than the pH of the IBF sample for each sampling event. Alkalinity was detected only in the Blaine IBF sample collected on November 14, 2012, but this result is considered erroneous due to the low pH (2.5). Metals and sulfate concentrations in Blaine samples were consistently higher than in samples from the 517 Shaft and the St. Louis Tunnel discharge as sampled at DR-3. OBF samples consistently had higher concentrations of many metals (including zinc, cadmium, manganese, and iron) and sulfate as compared to IBF samples for each sampling event.

#### **2.4.7 Blaine Contaminant Loading**

Blaine flume flow data and laboratory analytical results were used to estimate contaminant mass loading to the Humboldt Drift (Table 2-4). Analytical data for OBF water samples were combined with daily average flume flow rates to estimate mass per day contributions to the St. Louis Tunnel discharge. OBF water samples were collected out-by (downgradient) of both the flume and the “inflow” (see Section 2.4.5). Daily average flow rates were calculated from hourly water depth measurements based on the flow rating curve provided by the flume manufacturer (Attachment 3-1). To estimate potential mass loading effects from the “inflow,” an assumption was made that “inflow” flow rates may have been as great as measured flume flow rates. Therefore, the mass loading values presented in Table 2-4 provide estimated ranges for mass loading from the Blaine Tunnel to the Humboldt Drift, assuming both the daily average flume flow rate (lower end of the range) and two times the daily average flume flow rate (upper end of the range). These calculations assume that metals are conserved in mine water flowing through the system and that suspended sediments do not settle out of solution. These simplified loading comparisons do not account for attenuation of metals within the mine workings as pH increases to circumneutral during transport from the Blaine to the St. Louis Tunnel discharge.

To account for the many variables that may have governed the Blaine flume and “inflow” flow rates and concentrations, peak mass loading estimates (Table 2-4) were calculated using both the maximum observed analytical results, which typically coincided with the April 2013 sampling

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<sup>7</sup> The IBF location is into the mine (upstream), compared to the flume location.



event, and the maximum average daily flow rate, which occurred on January 18, 2013, for the limited set of available data. Although the highest flow rates and concentrations did not occur at the same time, these peak mass loading estimates are provided to assess higher mass loadings that could be produced by flow of mine water from this part of the Blaine Tunnel. Higher flow rates may indicate infiltration of less contaminated water (e.g., snow melt), and these higher flows could potentially react with metals in the mine workings, thereby increasing the dissolved metals concentrations.

The highest calculated contaminant loading rates coincided with the peak flow rates observed in September 2013, despite the relatively low metals concentrations observed during the September 2013 water sampling event (Table 2-4). Estimated mass loading ranges for total and dissolved iron and manganese all overlapped substantially with estimated peak mass loading ranges in September 2013. This indicates that periods of higher flow from the Blaine result in higher contaminant loading to the Humboldt Drift and the downstream portions of the workings, even if metals concentrations are lower.

Samples collected from the 517 Shaft (discussed in Section 4) tend to have lower metals concentrations and higher pH as compared to Blaine samples, indicating that mine water from the Blaine Tunnel is partially neutralized during transport to the SE Cross-cut. Some natural attenuation of metals also occurs between the Blaine Tunnel and the SE Cross-cut at the 517 Shaft as pH increases. Mine water from the Blaine Tunnel eventually drains via the SE Cross-cut to the St. Louis Tunnel and exits the mine workings at the St. Louis Tunnel portal near monitoring location DR-3. Thus, contaminant discharge rates from the Blaine Tunnel via the Humboldt Drift can be compared to contaminant discharge rates at DR-3 to assess the relative contribution from the accessible portion of the Blaine Tunnel.

Based on the availability of flow and analytical data for both the Blaine Tunnel and the St. Louis Tunnel discharge, metals loadings can be compared for April 25, June 12, July 10, and August 27, 2013. For these four sampling dates, contaminant discharge rates at DR-3 were calculated (Table 2-4). Contaminant loading rates from the Blaine Tunnel to the Humboldt Drift for select metals then were compared to contaminant discharge rates at DR-3 to conservatively estimate the proportion of contaminants contributed by the Blaine Tunnel source area (Table 2-4). These calculations assume that metals are conserved within the flow pathways, which may introduce significant uncertainty. The results were as follows.

- For the samples that were collected in April 2013, contaminant discharge from the Blaine Tunnel was equivalent to 6% to 12% of the total arsenic discharging from the

St. Louis Tunnel portal; 8.8% to 17% of the dissolved iron; and no more than 2.1% of the cadmium, manganese, zinc, and total iron.

- In June 2013 (before the start of NaOH injection to the 517 Shaft), contaminant discharge from the Blaine was slightly higher. Total arsenic discharge from the Blaine was equivalent to 7.5% to 15% of the total arsenic discharging from the St. Louis Tunnel portal; up to 4.1% of the cadmium; and no more than 3.1% of the total iron, manganese, and zinc. However, the rate of dissolved iron discharge from the Blaine Tunnel was substantially higher than the dissolved iron discharge rate at DR-3. Other observations have indicated that dissolved iron tends to attenuate by precipitation as iron oxides and oxyhydroxides within the mine workings, resulting in very low dissolved iron concentrations at the St. Louis Tunnel portal.
- The July 2013 sample from DR-3 was most likely affected by the injection test. Contaminant discharge from the Blaine Tunnel was equivalent to 21% to 46% of the total arsenic discharging at DR-3; up to 18% of the total iron; and less than 5% of the cadmium, manganese, and zinc. The rate of dissolved iron discharge from the Blaine Tunnel may have been up to two times the dissolved iron discharge rate at DR-3.
- For the August 2013 samples, contaminant discharge from the Blaine Tunnel was a larger contributor to the DR-3 contaminant discharge as the Blaine flow rate and mass discharge rate both increased. The Blaine Tunnel contributed 27% to 56% of the total arsenic discharging at DR-3; up to 20% of the total iron; up to 11% of the cadmium; less than 7% of the manganese; and no more than 6.4% of the zinc. The rate of dissolved iron discharge from the Blaine Tunnel may have been more than five times higher than the dissolved iron discharge rate at DR-3.

Based on this comparison of contaminant discharge rates from the Blaine and St. Louis Tunnels, the results indicate that the accessible portion of the Blaine Tunnel is not a major source area of cadmium, manganese, or zinc, but the area may be a significant source of arsenic and iron. The discharge rate of dissolved iron from this part of the Blaine is apparently higher than the dissolved iron discharge rate at the St. Louis Tunnel portal, indicating that the high concentrations of dissolved iron from the Blaine attenuate within the mine workings. These calculations do not account for non-measured flow increases or concentration changes during transport down the Humboldt Drift and do not consider contaminant loading from inaccessible areas of the overall Blaine workings.

## 2.5 OTHER SOURCE AREAS

In addition to the Blaine Tunnel source area, other mine workings that are located south of Silver Creek within Blackhawk Mountain may be additional source areas and may be interconnected to the Blaine Tunnel and/or the SE Cross-cut. This section summarizes available information about these areas.

### **2.5.1 Argentine Tunnel Workings**

As part of the source characterization activities conducted in 2011, the Argentine Tunnel was entered and investigated (URS, 2012). This tunnel is located south of Silver Creek above the Blaine Tunnel and may be a source of mine water that flows to the Blaine Tunnel and the underlying workings, based on interconnections apparent on historic mine maps. The mine entry team observed both pooled water and flowing water in the tunnel, with accumulations of sediment and sludge, which is thought to be iron oxyhydroxide; however, flow paths could not be determined in the field. Field-measured pH was between 2.0 and 2.5. One water sample that was collected from the Argentine Tunnel (referred to as the “Lower Acidic Pool”) had very high concentrations of some metals, indicating that the Argentine Tunnel and other workings above the Blaine Tunnel may be a substantial source of metals loading to the St. Louis Tunnel. Complete analytical results for this sample are provided in Table 4 of URS (2012).

Highlights of the analytical results for the Argentine Tunnel sample are as follows (URS, 2012).

- Total and dissolved cadmium were detected at 11,900 µg/L and 12,000 µg/L, respectively, approximately 12 to 25 times higher than concentrations detected in 2011 samples from the Blaine Tunnel.
- Total and dissolved manganese were detected at 270,000 µg/L and 294,000 µg/L, respectively, approximately 5 to 10 times higher than concentrations detected in 2011 samples from the Blaine Tunnel.
- Total and dissolved zinc were present at 2,390,000 µg/L and 2,460,000 µg/L, respectively, approximately 15 to 40 times higher than concentrations detected in 2011 samples from the Blaine Tunnel.

Based on in-tunnel observations and these analytical results, URS (2012) recommended additional study of the Argentine Tunnel to better characterize flow paths and contaminant concentrations. Based on currently available information, the contribution of contaminants from the Argentine Tunnel to mass discharge at the St. Louis Tunnel cannot be determined.

### **2.5.2 Other Mine Workings South of Silver Creek**

In addition to the Argentine Tunnel, extensive mine workings exist south of Silver Creek, particularly above the Blaine level. Although the existence of these workings is known and historic maps are available, these upper workings have not been recently assessed by direct field investigation. Historic mine maps indicate that essentially all of these mine workings are interconnected. The accessibility of these workings for direct entry and sampling is limited by steep hillsides. Collapsed portals and tunnels and generally unsafe conditions in the unmaintained workings also may prevent entry.

Although interconnections of these workings with the Blaine Tunnel and the SE Cross-cut likely are present, based on the historic mine mapping, they have not been confirmed in the field. Infiltration and mine water from these workings are believed to drain to the Blaine Tunnel and lower levels and eventually drain to the SE Cross-cut and the St. Louis Tunnel portal. However, the extent to which these workings contribute to volumetric and mass loading at the St. Louis Tunnel is unknown.

### **3.0 SOURCE WATER HYDRAULIC CONTROL**

This section briefly considers potential methods (e.g., plugging tunnels or grouting fractures) for reducing the mine water discharge rate at the St. Louis Tunnel portal by controlling the flow of water within the mine workings. Conceptually, reducing flow of mine water is one method for reducing the rate of contaminant discharge from the St. Louis Tunnel portal. The following discussions assume that the flow proportions reported by Anaconda (1982) are accurate.

#### **3.1 BLAINE TUNNEL**

The main Blaine Tunnel has a total length of about 3,750 feet (Burack, 1982). The safely accessible part of the Blaine Tunnel is limited to the no more than about 120 feet in-by the cofferdam, or about 470 feet from the portal (URS, 2012). Thus, most of the Blaine (100) level workings cannot be safely accessed and have not been investigated recently to characterize flows or contaminant loadings. Other than the Blaine Tunnel flume measurements discussed in Section 2.4, there is no information about sources of mine water or flow paths within the Blaine Tunnel.

The accessible part of the Blaine Tunnel contributes relatively small flows and mass loadings (with the exception of arsenic and iron, as shown in Table 2-4) via drainage to the Humboldt Drift. Hydraulic control of these flows or elimination of contaminant mass in flows to the Humboldt Drift would provide little benefit in reducing the overall flows or loadings at the St. Louis Tunnel and thus are not practical.

#### **3.2 SOUTHEAST CROSS-CUT**

Based on the August 1980 data, the SE Cross-cut is estimated to contribute about 67% of the flow and about 34% of the zinc that discharges from the St. Louis Tunnel (Anaconda, 1982). Access to the SE Cross-cut from the St. Louis Tunnel is not currently possible due to obstructions at the original St. Louis Tunnel portal area. Direct access from other mine workings to the south of the St. Louis Tunnel, such as the 517 Shaft or the Argentine Shaft, is not safe due to the vertical separation of about 450 feet from ground level near the 517 Shaft to the SE Cross-cut. Furthermore, plugging the SE Cross-cut to reduce discharge at the St. Louis Tunnel

may have unintended consequences. Hydraulic heads would increase to the south of any plug, which could result in increased groundwater discharge to Silver Creek or discharge of mine water at other locations, potentially increasing metals loading to Silver Creek, although such a hydraulic evaluation has not been conducted.

Mine workings to the south of Silver Creek drain to the SE Cross-cut, based on historic mine maps and tracer testing conducted in 2011 (URS, 2012). These mine workings are the source of a substantial fraction (although apparently not the majority) of the flow that discharges from the St. Louis Tunnel. Access to these mine workings (with the exception of the Argentine Tunnel) has not been attempted recently, and there is limited information about access conditions. Even if these mine workings could be accessed safely, establishing hydraulic controls within the mine workings south of Silver Creek to reduce flows at the St. Louis Tunnel portal would be very difficult to implement and maintain and may have unforeseen consequences.

Based on the current understanding, the SE Cross-cut and the mine workings that drain to the SE Cross-cut are not readily or safely accessible for establishing hydraulic controls. Although methods for controlling contaminant loading from the SE Cross-cut have been investigated (as described in Section 4), the feasibility of establishing hydraulic controls in these parts of the mine workings was not part of this investigation.

### **3.3 NORTHWEST CROSS-CUT**

The flows and loadings contributed by the NW Cross-cut have not been evaluated recently. Based on the August 1980 data, the NW Cross-cut is estimated to contribute about 25% of the flow and about 65% of the zinc discharging from the St. Louis Tunnel (Anaconda, 1982). Access to the NW Cross-cut from the St. Louis Tunnel is not currently possible due to obstructions at the St. Louis Tunnel portal area, and access from other mine workings to the north of the St. Louis Tunnel has not been assessed. The feasibility of establishing hydraulic controls in the mine workings to the north of the St. Louis Tunnel was not part of this investigation; thus, the potential for reducing or controlling flows and/or contaminants that are contributed by the NW Cross-cut cannot be assessed at this time.

### **3.4 145 RAISE**

The 145 Raise appears to be a dead-end raise and cannot be accessed for assessment. Based on the August 1980 data, the 145 Raise is estimated to contribute about 8% of the flow and less than 1% of the zinc that discharges from the St. Louis Tunnel (Anaconda, 1982). Access to the 145 Raise from the St. Louis Tunnel is not currently possible due to obstructions at the St. Louis Tunnel portal. Potential access from other mine workings to the north of the St. Louis Tunnel is currently not known but is judged to be very unlikely, based on available historic mine maps.

Therefore, the feasibility of reducing or controlling flows and/or contaminants that are contributed by the 145 Raise cannot be fully assessed but is judged to be low.

### **3.5 HYDRAULIC CONTROLS CONCLUSIONS**

The subsurface workings that are known to be safely accessible are the 517 Shaft Access Tunnel and the near portal reach of the Blaine Tunnel. The 517 Shaft Access Tunnel connects to the top collar of the 517 Shaft but does not provide direct access to mine water flowing through the SE Cross-cut. The Blaine Tunnel provides access to the mine water pool that drains to the Humboldt Drift, contributing a small fraction of the overall flow that discharges from the St. Louis Tunnel. Implementation of hydraulic controls at either of these locations is unlikely to substantially reduce volumetric or contaminant loading of the St. Louis Tunnel discharge.

For other areas that contribute to the St. Louis Tunnel discharge (i.e., NW Cross-cut, 145 Raise, and the workings to the south of Silver Creek above the Blaine level), methods for hydraulic control of mine water cannot be adequately evaluated due to lack of information on safe access. Even with safe access, substantial investigations would be needed to determine feasible locations and the likely future success or effects of hydraulic control measures.

Although the existence of major faults is known and infiltration through these features is presumed to occur, evaluations of their accessibility for grouting, their distribution and extent, and the extent to which grouting would reduce water flow to the St. Louis Tunnel was beyond the scope of this investigation. The feasibility of effectively reducing infiltration to the mine workings and reducing flow at the St. Louis Tunnel by this method cannot be evaluated currently.

## **4.0 SOURCE WATER CONTAMINANT CONTROL**

The following sections briefly describe the results of a treatability study conducted in 2012 and 2013 to evaluate the hydraulics, water chemistry, and potential source control measures at the 517 Shaft. The treatability study included geophysical characterization of the 517 Shaft, injection of alkaline solutions into the shaft to precipitate metals in source water from the Blaine-Argentine mine workings, and tracer studies to evaluate the hydraulic characteristics of the mine workings between the shaft and the St. Louis Tunnel. Complete results will be presented in a forthcoming injection test completion report.

### **4.1 GEOPHYSICAL CHARACTERIZATION OF THE 517 SHAFT**

Geophysical characterization of the 517 Shaft was conducted by Layne Christensen Company – Colog Division (Colog) in 2012 and 2013, prior to commencing each of the 2012 and 2013



injection tests. The goals of these surveys were to determine the hydraulic characteristics of the 517 Shaft; evaluate the geometry and physical conditions of the shaft and the stratification of water chemistry; and provide pre-injection test water quality data. Additionally, the 2013 characterization work documented 517 Shaft conditions during the spring run-off period, when snowmelt and surface water flow rates were anticipated to be at or near the annual peak. This section briefly describes the survey methods and findings. Additional details are provided in the 2012 and 2013 summary reports included as Attachments 4 and 5, respectively.

#### **4.1.1 Methodology**

The 517 Shaft characterization work conducted in 2012 included downhole video logging of the shaft, vertical logging of water quality parameters, measurement of vertical flow velocities in the submerged portion of the shaft, and collection of discrete water samples at two depths. This work was performed during the first week of September 2012. Similar characterization efforts were conducted in 2013, with additional measurement of horizontal flow velocities and water quality parameters, collection of water samples at discrete depths throughout the submerged portion of the shaft, and deployment of a sonar system to develop a three-dimensional image of the submerged portion of the shaft, where video quality was limited due to the turbid mine water. All tools and equipment for the geophysical characterization efforts were lowered into the 517 Shaft from a pulley mounted on an A-frame structure above the collar of the 517 Shaft lift-access chamber (see photograph in Attachment 5-2).

Video logs of the 2012 and 2013 shaft surveys are included on digital video discs included with Attachments 4 and 5, respectively.

#### **4.1.2 Physical Conditions**

The 517 Shaft is located approximately 220 feet in-by the 517 Shaft Access Tunnel portal (Figure 1 and Attachment 1). Video logging of the 517 Shaft indicated that the shaft is fully timbered and consists of two vertical chambers, each with a cross-sectional area of approximately seven feet by seven feet. One chamber provided lift access to lower levels of the historic mine workings, while the other chamber enclosed a series of ladders and served as a manway. Platforms were constructed within the ladder chamber at approximately eight-foot vertical intervals.

The total depth of the shaft is approximately 622 feet,<sup>8</sup> and the depth to water was approximately 453 feet during both 2012 and 2013 characterization efforts.<sup>9</sup> Based on these measurements, approximately the lower 170 feet of the 517 Shaft are flooded.

Video and sonar observations indicated that at least four different mine workings levels may intersect the 517 Shaft at various depths. Features at the following distances below the shaft collar were noted:

- 14 feet – observed horizontal tunnel with rail tracks and rail car
- 90 feet – 200 level tunnel intersection observed to the northeast (NE)
- 209 feet – 300 level tunnel intersections observed to the NE and southwest (SW)
- 351 feet – 400 level tunnel intersections observed to the NE and SW
- 452 feet – 500 level tunnel intersections observed to the NE and SW; observed a sheave near the top of the tunnel within the ladder chamber
- 453 feet – surface of pooled mine water
- 464-472 feet – observed collapsed beams and an absence of the ladder chamber, potentially indicating a tunnel intersection
- 494 feet – deepest observation of the ladder chamber; lift guides still visible below this depth
- 503-506 feet – observed collapsed beams; large voids absorbed acoustic signal; potential tunnel intersection
- 523-527 feet – deepest extent of camera and flow meter advancement due to collapsed timbers obstructing the shaft; large voids absorbed acoustic signal; potential tunnel intersection
- 536 feet – deepest extent of sonar advancement due to collapsed timbers obstructing the shaft
- 622 feet – deepest extent of the 517 Shaft

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<sup>8</sup> All 517 Shaft depth measurements are approximate and are provided as measured from the shaft collar at the ground surface of the 517 Shaft Access Tunnel portal.

<sup>9</sup> All depths presented herein are referenced to the shaft collar, as presented in the 2013 Colog report (Attachment 5).



#### **4.1.3 Water Quality**

Vertical profiles of water quality parameters were collected in 2012 and 2013 using the methods and instrumentation described in Attachments 4 and 5. The following notable trends were observed in water quality parameters.

- Fluid temperature generally increased with depth for approximately the first 20 feet below the water surface, indicating that heat is lost from the surface of the pool or that water dripping into the 517 Shaft from above was much colder than mine water pooled within the shaft.
- Water quality parameters in both 2012 and 2013 changed abruptly between the depths of 490 feet and 500 feet and at approximately 523 feet deep. In 2012 (Appendix A in Attachment 4), dissolved oxygen decreased at about 497 feet (corresponding to an apparent outflow from the shaft). Fluid conductivity decreased at 523 feet (corresponding to apparent inflow to the shaft) in the 2012 survey, but increased at a depths between 520 and 525 feet during the 2013 survey (Appendix A in Attachment 5). The conductivity stratification in 2013 may indicate the presence residual alkaline solution that was injected into the shaft during 2012.
- ORP was measured consistently between approximately 100 millivolts (mV) and 200 mV. A slight drop in ORP was noted at a depth of about 497 feet during the 2013 survey, corresponding to an apparent outflow from the shaft.
- pH was generally consistent with depth. In 2012, pH was approximately 5.6 throughout the water column. In 2013, pH ranged between approximately 6.7 and 7.0. The slightly higher pH in 2013 may indicate lingering impacts of the alkaline solution injections during autumn 2012 (Section 4.2).

#### **4.1.4 Flow Observations**

Flow measurements, vertical profiling of water quality parameters, and video and sonar observations were compared to identify depths at which mine water may enter or exit the 517 Shaft. Methodology and instrumentation are described in Attachments 4 and 5. The flow measuring devices deployed in 2012 and 2013 were unable to quantify flow rates within the 517 Shaft because the cross-sectional area of the shaft is neither consistent nor well established. However, the flow measurements did indicate general flow directions and relative magnitudes. Differences in flow direction as a function of depth were generally supported by anomalies in the water quality parameter vertical profiles. Flow data are included in Attachment 5.

Both 2012 and 2013 observations indicated that water in the 517 Shaft flows generally upward and out at or near the water surface (453 feet deep), thought to coincide with the St. Louis Tunnel (500) level. Measurements in 2013 further indicated that flow leaving the shaft was

generally to the northeast, corresponding to the direction in which mine workings connect to the SE cross-cut, as indicated on historic maps (Attachment 1).

In 2013, downward flow was observed within the top foot of the water column in the 517 Shaft, possibly due to mixing caused by water dripping into the pooled mine water from above. Other observed variations in flow velocity (in 2013) and direction (in 2012) may be indicative of water entering and exiting the 517 Shaft at multiple depths below the pool surface, or it may indicate that flow from the 517 Shaft is minimal except during periods of winter snowmelt or heavy precipitation. Vertical flow data from 2012 indicated that water diverged at a depth of approximately 470 feet, indicating that water may enter the shaft at this depth. This depth coincided with collapsed timbers observed between 464 feet and 472 feet.

Water was also observed to converge at a depth of approximately 495 feet, indicating that water may exit the shaft at this depth. This depth coincided with the terminal depth of the ladder chamber, the abrupt change in water quality parameters observed between 490 feet and 500 feet, and a notable decrease in fluid velocity around 490 feet. Below approximately 525 feet, mine water appears to be stagnant or pooled. Therefore, it is not expected that a substantial source of water enters or exits the 517 Shaft from a depth below 525 feet.

#### **4.2 2012 INJECTION TEST**

The 2012 treatability study was conducted over 42 days between September and November 2012 to evaluate the effectiveness of chemical addition for increasing alkalinity and pH of mine water in the 517 Shaft, and precipitating metals inside the mine workings in order to reduce the dissolved metals load in water that discharges from the St. Louis Tunnel. A 23.5% potassium carbonate ( $K_2CO_3$ ) solution was injected below the water surface in the 517 Shaft for the entire test. Starting on day 21, water from Silver Creek was injected at about 25 gpm as carrier water due to low flows through the mine workings. During the final week, a 25% sodium hydroxide (NaOH) solution was injected. Both the Silver Creek water and the NaOH solution were discharged from an injection pipe at the shaft collar.

Injection totals were as follows: 22,700 gallons of  $K_2CO_3$  solution; 330 gallons of NaOH solution; and 626,800 gallons of Silver Creek water. Water quality parameters were continuously monitored throughout the test and water samples were collected periodically from the 517 Shaft and the St. Louis Tunnel portal area (monitoring location DR-3A, located downstream of the portal and upstream of existing monitoring location DR-3; Figure 1-2).

#### 4.2.1 517 Shaft Results

Injection of  $K_2CO_3$  into the 517 Shaft rapidly increased the pH and alkalinity and decreased metals concentrations in mine water pooled within the shaft (Figure 4-1). The pH in the 517 Shaft increased from pH 6.1 to as high as pH 10.7 with injection of  $K_2CO_3$  and as high as pH 11.7 with the injection of  $K_2CO_3$  and NaOH during the final week of the test (Figure 4-1). The total alkalinity increased from approximately 30 mg/L as calcium carbonate ( $CaCO_3$ ) to approximately 3,000 mg/L as  $CaCO_3$  with injection of  $K_2CO_3$ . Concurrent injection of NaOH and  $K_2CO_3$  resulted in minimal further alkalinity increases (Figure 4-1), although the form of alkalinity shifted from predominately bicarbonate to carbonate. Much of the alkalinity injected as  $K_2CO_3$  was apparently lost to softening mechanisms, primarily the precipitation of calcium as  $CaCO_3$ . Metals concentrations in the 517 Shaft generally decreased in response to injection (Figure 4-1). Injection of  $K_2CO_3$  decreased many metals concentrations in the 517 Shaft by about 90%, and injection of  $K_2CO_3$  and NaOH decreased many metals concentrations by about 95%. Concentrations of dissolved cadmium, manganese, and zinc in the 517 Shaft were reduced to less than their respective reporting limits by the end of the injection. Metals concentrations partially rebounded within one week after injection stopped.

#### 4.2.2 St. Louis Tunnel Discharge Results

At DR-3A, pH increases were no more than 0.3 standard unit from about pH 6.7 to 7.0 in response to  $K_2CO_3$  and NaOH injection (Figure 4-2), in contrast to an increase of pH 4.6 to 5.6 at the 517 Shaft, due to dilution and neutralization within the flow system between the 517 Shaft and the St. Louis Tunnel discharge. Total alkalinity at DR-3A (in the form of bicarbonate alkalinity only) increased by 22% during the first two weeks of injection, but increased doses of  $K_2CO_3$  and injection of NaOH did not further increase alkalinity at DR-3A (Figure 4-2). Zinc and cadmium concentrations at DR-3A decreased by up to 40%, and manganese concentrations decreased by up to 25%. Concentrations partially rebounded during the post-injection monitoring phase (Figure 4-2). The greatest reductions of metals concentrations at DR-3A occurred during the first two weeks of  $K_2CO_3$  injection; the increased  $K_2CO_3$  dose and later injection of NaOH did not substantially increase metals removal upstream of DR-3A.

These results indicate that injection of  $K_2CO_3$  to the 517 Shaft provided sufficient excess alkalinity to reduce concentrations of zinc, cadmium, manganese, and other metals at the St. Louis Tunnel discharge. The subsequent injection of NaOH was insufficient to further increase the alkalinity and pH or to further decrease metals concentrations at DR-3A. The alkalinity added during  $K_2CO_3$  injection was not sufficient to substantially raise the pH at DR-3A or to precipitate more than 40% of the target metal contaminants in the mine workings between the 517 Shaft and DR-3A. The loss of alkalinity was most likely due to softening mechanisms

(i.e., precipitation of calcium as  $\text{CaCO}_3$ ) and sinking of the dense injection solution in the 517 Shaft. The injection location was more than 45 feet below the water surface due to injection hose stretch, exacerbating the loss of alkalinity to the lower part of the shaft. The injection was suspended before higher injection rates could be tested, due to the onset of winter weather conditions.

#### **4.3 2013 INJECTION TEST**

Follow-on injection testing was conducted between June 21 and July 9, 2013, to further evaluate chemical injection to the 517 Shaft as a method for reducing concentrations of metals in the St. Louis Tunnel discharge. In an attempt to provide sufficient alkalinity to treat mine water between the 517 Shaft and the St. Louis Tunnel discharge while minimizing carbonate addition and preventing losses of carbonate alkalinity to softening (i.e., precipitation of  $\text{CaCO}_3$ ), as was observed during 2012, 25% NaOH solution was injected below the water surface in the 517 Shaft over 18 days in 2013. Additional tracer testing also was performed.

Approximately 4,180 gallons of 25% NaOH solution (equivalent to about 11,200 pounds of NaOH) and 395,000 gallons of Silver Creek water were injected into the 517 Shaft. Water quality parameters were continuously monitored and water samples were collected periodically from the 517 Shaft and DR-3A. Although the 2013 injection test was planned for a longer duration than the 2012 injection test to allow equilibrium concentrations to be established at DR-3A, the 2013 injection test was stopped after 18 days of injection due to failure of an injection system valve and a resulting release of NaOH solution onto the floor of the 517 Shaft Access Tunnel. The media affected by the NaOH were subsequently neutralized.

##### **4.3.1 517 Shaft Results**

Injection of NaOH increased the pH and alkalinity and significantly decreased metals concentrations in the 517 Shaft mine water pool (Figure 4-3). The pH of water in the 517 Shaft increased from pH 6.8 to 8.9 within 20 hours of starting NaOH injection and increased to a peak of pH 12.8 within two weeks of the start of the injection. The addition of Silver Creek water likely improved mixing of NaOH within the shaft, resulting in higher measured pH. Total alkalinity in the 517 Shaft increased from approximately 252 mg/L as  $\text{CaCO}_3$  to 978 mg/L as  $\text{CaCO}_3$  after 18 days of injection, and the predominant form of alkalinity shifted from bicarbonate to 53% carbonate alkalinity and 47% hydroxide alkalinity. The alkalinity increase in the 517 Shaft during the 2013 NaOH injection test (Figure 4-3) was considerably less than the alkalinity increase observed during the 2012 injection of  $\text{K}_2\text{CO}_3$  (Figure 4-1), possibly due to different mixing characteristics during each test. As was observed in 2012, alkalinity and pH decreased gradually during post-injection monitoring (Figure 4-3).

Metals concentrations and sulfate in the 517 Shaft generally decreased in response to NaOH injection but rebounded after NaOH injection was terminated (Figure 4-3). Based on a comparison of the 517 Shaft sample collected two days prior to the start of the injection (June 19) and the sample collected at the end of the injection (July 9), concentrations of total cadmium, manganese, and zinc decreased by at least 76%, and concentrations of dissolved cadmium, manganese, and zinc decreased by at least 95% (Figure 4-3). Similar results were observed for calcium, but magnesium concentrations decreased to a lesser extent. Sulfate in the 517 Shaft decreased by 94%, possibly due to precipitation with calcium.

#### **4.3.2 St. Louis Tunnel Discharge Results**

At DR-3A, pH increased slightly from pH 6.8 pre-injection to a maximum of pH 7.0 at the end of the injection (Figure 4-4). Similar to the 2012 injection test, the small pH change relative to that observed at the 517 Shaft was likely due to neutralization of alkaline chemicals as the alkaline-solution amended mine water flowed through the mine workings between the 517 Shaft and DR-3A. Alkalinity at DR-3A (bicarbonate only) increased by about 24% during injection and continued to increase during the post-injection monitoring period (Figure 4-4). Much of the alkalinity injected into the 517 Shaft as NaOH was apparently lost due to neutralization within the mine workings or precipitation of non-target metals, such as aluminum. Some of the dense NaOH solution likely sank in the shaft due to inadequate mixing at the injection point, which was more than 45 feet below the water surface due to injection hose stretch. Since alkalinity was lost to the bottom of the shaft, there appears to have been an insufficient dose to adequately treat waters entering the system from the NW Cross-cut or the 145 Raise. The post-injection alkalinity increase at DR-3A may have been caused by slow flushing of NaOH from the shaft after injection was terminated.

Despite the limited increase in pH and alkalinity at DR-3A, total cadmium, zinc, and manganese concentrations at DR-3A were decreased by up to 26%, 20%, and 11%, respectively (Figure 4-4). Total iron was reduced by up to 55%, but concentrations of total calcium and total magnesium were reduced by no more than 10%. These results indicate that much of the contaminant loading contributed to the St. Louis Tunnel by the SE Cross-cut was eliminated by injection of NaOH at the 517 Shaft.

#### **4.4 2012-2013 TRACER TEST RESULTS**

Tracer testing during the 2012 and 2013 injection tests confirmed that a hydraulic connection exists between the 517 Shaft and the St. Louis Tunnel discharge and provided information about the hydraulic characteristics of the mine workings. The following sections present a brief

summary of 2012 and 2013 tracer test activities and results; additional results and discussion will be included in the forthcoming injection test completion report.

#### **4.4.1 2012 Tracer Test Results**

Lithium chloride solution was continuously injected into the 517 Shaft for the first 12 days of the 2012 injection test, concurrent with the injection of  $K_2CO_3$ . During that time, both lithium and chloride increased and slowly approached their expected equilibrium concentrations at DR-3A (Figure 4-5). About 64% of the injected lithium was recovered at DR-3A during the monitoring period, whereas less than 1% of injected chloride was recovered, most likely due to the relatively high chloride detection limit (0.5 mg/L), which prevented quantification of low chloride concentrations early in the tracer test.<sup>10</sup> Lithium that was not recovered may have been stored in the 517 Shaft mine water pool, below the 500 level discharge to the SE Cross-cut and the St. Louis Tunnel.

The tracers injected into the 517 Shaft in 2012 were slow to appear at DR-3A in comparison to a previous tracer test. URS (2012) reported that tracers injected into the 517 Shaft first appeared at DR-3A in about 15 hours, while peak tracer concentrations arrived in 21 to 37 hours. The mean hydraulic residence time (HRT) between the 517 Shaft and DR-3A based on the October 2011 pulse injection tracer test was about 9.3 days, whereas the mean HRT during the 2012 injection test was approximately 10.8 days. In the 2012 continuous injection tracer test, elevated lithium concentrations first were observed about 2 to 3 days after the start of injection, and peak concentrations were observed about 13 days after the start of injection (Figure 4-5). The shorter travel time reported by URS (2012) likely was due to rapid injection of 50,000 gallons of chase water into the 517 Shaft immediately following tracer injection, which would have rapidly flushed the tracer out of the 517 Shaft and into the SE Cross-cut. During the 2012 tracer test, the tracer solution was injected at a slower rate with considerably less volume. Lithium chloride was injected with about 6,900 gallons of  $K_2CO_3$  solution at a maximum flow rate of 0.6 gpm, with no additional chase water.

#### **4.4.2 2013 Tracer Test Results**

Sodium was continuously injected as NaOH for the duration of the 2013 injection test, and sodium concentrations were monitored in the 517 Shaft before and after injection (Figure 4-6). Post-injection sodium concentrations in the 517 Shaft decreased exponentially. Reactor modeling of post-injection sodium concentrations in the 517 Shaft indicates that the mean HRT in the shaft is more than 18 days under natural (no injection) flow conditions. These calculations

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<sup>10</sup> The expected chloride concentration was about 2 mg/L (as shown in Figure 4-5), but the method detection limit for chloride was 0.5 mg/L.



assume that the 517 Shaft was a completely mixed reactor with constant volume and clean inflow under post-injection conditions. Under these conditions, the residual sodium would be flushed slowly from the system, and the concentration would decrease over time. The mean HRT of more than 18 days supports other observations that suggest that natural flow through the 517 Shaft and into the SE Cross-cut is limited.

The expected sodium equilibrium concentration at DR-3A was about 75 mg/L, based on the NaOH injection rate, background sodium concentration, and flow rate recorded at DR-3. The highest sodium concentration detected at DR-3A was 38 mg/L on July 9, or about 51% of the expected equilibrium concentration (Figure 4-6). Numerical integration of the DR-3A sodium concentrations and flow rates indicate that only 49% of the injected sodium exited the St. Louis Tunnel portal during the monitoring period (June 21 to September 16). Assuming that sodium is nonreactive within the mine workings, the low sodium recovery indicates that half of the injected sodium remained within the mine workings, possibly due to poor mixing and storage of NaOH in the 517 Shaft, sinking of the dense NaOH solution in the 517 Shaft, or sorption of sodium ions to mineral surfaces within the mine workings. Since sodium did not approach equilibrium at DR-3A, sodium results cannot be used to estimate the mean HRT of the mine workings between the 517 Shaft and DR-3A under the conditions of the 2013 injection test.

#### **4.5 POTENTIAL FOR SLUDGE GENERATION**

In-situ chemical precipitation of metals will reduce dissolved concentrations of metals in drainage that discharges from the St. Louis Tunnel and will generate metal precipitate sludge within the mine workings. The settleability of precipitated metals and the potential sludge storage volume within the mine workings are not known; therefore, the quantity of precipitated metals that may be retained within the mine workings is unknown. This section estimates sludge generation rates for two in-situ treatment scenarios: complete treatment of the flow that discharges from the St. Louis Tunnel and treatment of the SE Cross-cut only. These estimates can be used for assessing the potential longevity of underground sludge storage, as well as future requirements for sludge disposal outside the St. Louis Tunnel if underground sludge storage capacity is fully utilized.

The following assumptions were made for these sludge generation estimates:

- Flow at DR-3 is assumed to be 530 gpm, based on a manual flow measurement from June 12, 2013. The flow proportions presented by Anaconda (1982; see Section 2.2) based on 1980 observations are accurate. Thus, the flow from the SE Cross-cut is about 353 gpm (2/3 of the flow at DR-3), and combined flow from the NW Cross-cut and 145 Raise is about 177 gpm.

- Pre-injection concentrations in samples acquired during 2013 from DR-3 and the 517 Shaft are representative of system baseline conditions. Samples from the 517 Shaft are assumed to represent mine water flowing through the SE Cross-cut.
- Calcium and magnesium will both precipitate after chemical injection, consistent with 2012-2013 injection test observations. Magnesium hydroxide and  $\text{CaCO}_3$  are included in the sludge generation estimates.
- Other target metals that are assumed to precipitate as hydroxides are iron, cadmium, zinc, aluminum, and copper. Manganese is assumed to precipitate as manganese carbonate. Other metals that are present at lower concentrations are not considered, and sodium, potassium, and lithium are assumed to produce no sludge.
- Treatment efficiency is not considered. An assumption of complete precipitation of the target metals will result in a conservative, worst-case sludge production estimate.

The maximum amount of sludge production would occur when all metals in the discharge from DR-3 are precipitated. This scenario applies to a treatment system constructed at the St. Louis Tunnel outlet and to an in-situ approach that injects sufficient alkaline chemical to precipitate all metals from both the SE and NW Cross-cuts. Based on the contaminant mass discharge rate at DR-3 (product of flow rate and concentration), about 1,800 pounds per day (lbs/day) of metals are discharged, but nearly 4,500 lbs/day of sludge would be generated (Table 4-1). Higher flow rates would yield proportionately higher sludge generation rates, assuming concentrations of metals and flow proportions remained constant. The estimated sludge mass consists mostly of  $\text{CaCO}_3$  (89% of the sludge mass) and magnesium hydroxide (7% of the sludge mass).<sup>11</sup> Less than 2% of the estimated sludge mass would be from removal of the main metals of interest (cadmium, manganese, and zinc). Precipitated solids could be settled from the St. Louis Tunnel effluent, if insufficient sludge storage volume is available in the mine workings.

A separate scenario assumes that sludge is generated by in-situ treatment of only the SE Cross-cut flow (similar to the 2012-2013 injection tests), while flow from the NW Cross-cut remains untreated. The flow proportions corresponding to the 1980 Anaconda observations (Section 2.2) are assumed, and the SE Cross-cut is assumed to have metals concentrations equal to the 517 Shaft sample collected on June 19, 2013. At a DR-3 flow rate of 530 gpm, approximately 1,500 lbs/day of metals would be removed, corresponding to about 3,600 lbs/day of sludge production (Table 4-1). More than 90% of this estimated sludge production is from precipitation of calcium. Under this scenario ("517 Shaft Treatment Scenario" in Table 4-1), the zinc concentration and loading at DR-3 would be reduced by about 46%, cadmium would be

<sup>11</sup> Actual sludge mass would be dependent on final pH achieved within the system. These estimates assume a worst-case sludge production scenario in which all metals precipitate and no precipitates are re-dissolved. In reality, actual sludge production would depend on many geochemical interactions.



reduced by 27%, and manganese would be reduced by 42%. Other metals would be reduced by 5% to 85% by eliminating metals from SE Cross-cut.

Based on these calculations, in-situ precipitation of metals likely would result in substantial sludge generation rates, and much of the generated sludge would consist of calcium and magnesium solids. The available sludge storage volume within the mine workings is currently not known but is assumed to be finite.<sup>12</sup> Development of methods to avoid softening mechanisms and prevent precipitation of non-target metals could reduce sludge generation rates, but in-situ chemical precipitation most likely would require a supplemental solids removal process to eventually be placed downstream of DR-3 for effective solids capture.

Further analysis of potential sludge generation rates under different in-situ treatment scenarios will be presented in the forthcoming injection test completion report.

#### **4.6 INJECTION TEST CONCLUSIONS**

As discussed in Sections 4.2 and 4.3, the 2012 and 2013 injection tests provided useful information about in-situ chemical precipitation. In response to injection of alkaline solutions, total alkalinity and pH increased in the 517 Shaft. Injection of  $K_2CO_3$  reduced metals concentrations in the 517 Shaft by about 90%, concurrent injection of NaOH and  $K_2CO_3$  reduced metals concentrations by about 95%, and injection of NaOH alone (during the 2013 test) reduced total metals by at least 76% and dissolved metals by at least 95%. At DR-3A, metals concentrations were reduced by up to 40% during the 2012 injection of  $K_2CO_3$  and by as much as 26% during the 2013 injection of NaOH. During both tests, total alkalinity in DR-3A samples increased no more than 24%, and pH increases were minimal. Based on historical observations of flows and zinc loadings (Section 2.3), most of the contaminant load from the SE Cross-cut was treated during both injection tests, and some of the contaminant load from the NW Cross-cut may have been treated during the 2012 test due to higher inputs of alkalinity. Metals concentrations in the 517 Shaft and at DR-3A partially rebounded after injections were terminated.

During both tests, much of the injected chemical did not treat target metals due to non-optimal chemical delivery (i.e., poor mixing and loss of chemical within the 517 Shaft), neutralization within the mine workings, and precipitation of non-target metals (i.e., calcium, magnesium, and

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<sup>12</sup> AECOM (2013b) estimated that the available volume of the mine workings is about 600,000 cubic feet from the St. Louis Tunnel portal area up to, but not including, workings at or above the Blaine level. This estimate includes the St. Louis Tunnel, cross-cuts, 517 Shaft, and Blaine-Argentine 500 through 200 levels open haulageway areas. This estimate does not include stoped areas that likely amount to substantially greater volume of openings; these openings likely are not where settling of precipitates would occur efficiently.

aluminum). As indicated by poor recovery of tracer ions in both tests, some of the dense alkaline solution likely sank into the pooled water in the 517 Shaft before mixing. The 517 Shaft is a non-ideal injection location because of the large water volume below the injection point and the location of the shaft at the end of a short, upward-sloping drift approximately 150 feet off the main 500 level workings (Figure 3 of Attachment 1). These factors, in addition to injection about 30 feet deeper in the 517 Shaft water column than intended due to stretching of the injection hose, prevented alkaline solutions from directly treating mine water in the SE Cross-cut and resulted in an insufficient dose to completely treat water from both the SE and NW Cross-cuts.

In summary, injection of  $K_2CO_3$  to the 517 Shaft reduced concentrations of zinc, cadmium, manganese, and other metals at the St. Louis Tunnel discharge by increasing pH and providing sufficient alkalinity for in-situ precipitation at the 517 Shaft and in the SE Cross-cut. Additional details of the 2012-2013 injection tests will be presented in a forthcoming injection test completion report.

If other water treatment alternatives that currently are being evaluated for the site do not provide sufficient treatment for the St. Louis Tunnel discharge, in-situ chemical precipitation could be developed further. Future investigation and improvements to the injection approach potentially could include:

- Other injection location(s) could be considered for treating the SE Cross-cut. The 517 Shaft is accessible under current conditions but has limited flow due to its location on a drift off the SE Cross-cut (Figure 3 of Attachment 1). Injection of carrier water probably would be required to effectively mix chemicals into the SE Cross-cut. The shaft also has a water column that extends for about 170 feet below the SE Cross-cut level, allowing some of the injected chemical to sink or treat non-target mine water below the injection point, regardless of injection depth. Direct injection into the SE Cross-cut could provide more efficient treatment of mine water, although this would require installation of a boring in the vicinity of the Argentine Shaft or other location above the SE Cross-cut (Figure 3 of Attachment 1).
- Other injection location(s) could be considered to treat water from the NW Cross-cut. Historic observations indicate that the NW Cross-cut contributes about 25% of flow and possibly more than 60% of zinc loading at the St. Louis Tunnel discharge. Injection locations other than the 517 Shaft, such as unexplored areas north of the St. Louis Tunnel, could be evaluated to avoid neutralization of injected chemicals during transport in the SE Cross-cut and to more directly treat the NW Cross-cut.
- Injection and tracer testing could be conducted for a longer duration to allow the system to approach steady state conditions. Longer-term testing would allow evaluation of this treatment approach under different seasonal conditions and would provide better geochemical and hydraulic characterization of the system. Additional testing would generate information that would allow prediction of effluent

concentrations and sludge production, while allowing a determination of the sustainability of this approach.

- Other chemical injection strategies could be considered. Continuous injection of  $K_2CO_3$  and NaOH solutions effectively increased pH and alkalinity and decreased metals concentrations, but continuous injection is relatively expensive and logistically challenging. Periodic dosing with a solid alkalinity source (e.g., soda ash briquettes) could be considered as a less expensive and relatively low maintenance method for implementing in-situ chemical precipitation, particularly if the alkalinity source could be placed directly into one of the cross-cuts. This method could be implemented periodically during periods of peak metals discharge (i.e., high flow and/or high metals concentrations).
- If treatment in the 517 Shaft is conducted in the future, then the injection system design should be improved to eliminate injection hose stretch, optimize injection location, and improve mixing of injected chemicals into the water to be treated.

## **5.0 CONCLUSIONS AND RECOMMENDATIONS**

The following sections present conclusions and recommendations for hydraulic and contaminant control methods, based on currently available information.

### **5.1 HYDRAULIC CONTROL METHODS**

Based on available information on flow contributions to the St. Louis Tunnel, most of the flow is contributed by the SE Cross-cut, with estimates ranging from 39% to 82% of the total flow at the St. Louis Tunnel portal. The NW Cross-cut is believed to contribute 12% to 25% of the total flow, and the 145 Raise is thought to be a minor contributor (less than 10%). Inflow to the St. Louis Tunnel through fractures and/or drill holes between the portal and the tunnel intersection may contribute some of the flow discharging from the portal. Measurable flows from the accessible part of the Blaine Tunnel are a minor contributor to the overall flow at DR-3. Most areas of the subsurface workings are not accessible currently, so no recent flow measurement or other data exists to verify flow contributions from different parts of the mine workings.

Due to a lack of recent information on flows through the workings, there is little information with which to evaluate hydraulic controls. Based on currently available information, there are no readily accessible locations to install bulkheads or plugs to control flows. Hydraulic control measures in the accessible part of the Blaine Tunnel would not reduce the hydraulic or contaminant loading at the St. Louis Tunnel significantly. If hydraulic controls could be installed safely, the potential effects are currently unknown. As water is stored behind the control structure, the increased hydraulic head throughout the upgradient portions of the mine workings could lead to unforeseen consequences, such as flow along alternate underground flow paths and eventual uncontrolled leakage from the mine workings, with impacts to surface waters or

shallow alluvial groundwater. Although the existence of major faults is known and infiltration through these features is presumed to occur, evaluations of their accessibility for grouting, their distribution and extent, and the extent to which grouting would reduce water flow to the St. Louis Tunnel was beyond the scope of this investigation.

## **5.2 CONTAMINANT CONTROL METHODS**

Injection of alkaline solutions to the 517 Shaft increased total alkalinity and pH and reduced metals concentrations in the 517 Shaft. Metals concentrations at the St. Louis Tunnel portal were reduced by up to 40% during the 2012 injection of  $K_2CO_3$  and by as much as 26% during the 2013 injection of NaOH, with minor pH increases. Most of the contaminant load from the SE Cross-cut was treated during both injection tests, and some of the contaminant load from the NW Cross-cut may have been treated during the 2012 test due to higher inputs of alkalinity.

In-situ chemical precipitation could be improved by altering the injection location (if possible) to directly treat the main flows and by increasing mixing energy at the injection point. These improvements would allow more effective injection to directly treat a larger proportion of the mine water from the SE and NW Cross-cuts and could avoid excessive neutralization of injected chemicals during transport within the mine workings. Other injection location(s) could be considered for treating water from the NW Cross-cut, which appears to contribute the highest contaminant mass fraction to the St. Louis Tunnel. Other chemical injection strategies, such as campaign treatment, could be considered for in-situ treatment of flows from the SE or NW Cross-cuts during periods with the highest rates of metals discharge.

Although in-situ chemical precipitation can partially reduce effluent concentrations at the St. Louis Tunnel portal, sludge generation rates would be substantial, particularly due to precipitation of non-target metals, such as calcium and magnesium. Methods for reducing the precipitation of non-target metals may improve treatment efficiency while minimizing solids generation. Since the finite sludge storage volume within the mine workings will eventually be exceeded, in-situ chemical precipitation will provide, at best, a partial or interim solution for reducing the rate of metals discharge from the St. Louis Tunnel.

No further testing of in-situ chemical treatment is recommended at this time. If other water treatment alternatives that currently are being evaluated for the site do not provide sufficient treatment for the St. Louis Tunnel discharge, in-situ chemical precipitation potentially could be revisited. Future field investigations and further development of this treatment method could include the items described in Section 4.6 to better understand the flow and contaminant contributions from different parts of the mine workings and improve the injection location and chemical delivery methods.

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**TABLES**

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**TABLE 2-1**  
**HISTORICAL FLOW PROPORTIONS AND ANALYTICAL**  
**RESULTS FOR INPUTS TO THE ST. LOUIS TUNNEL**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Parameter <sup>1</sup>	SE Cross-cut <sup>2</sup>	NW Cross-cut <sup>3</sup>	145 Raise <sup>4</sup>	St. Louis Portal <sup>5</sup>	St. Louis Adit Discharge <sup>6</sup>
Estimated Flow Proportion <sup>7</sup>	67%	25%	8%	100%	<i>not reported</i>
pH <sup>8</sup>	1.7	2.0	1.8	1.8	7.0
Fluoride (mg/L)	2.7	18	1.7	4.3	5.8
Sulfate (mg/L)	544	1,070	505	562	620
Total Zinc (mg/L)	2.62	27	0.50	5.2	5.00
Total Iron (mg/L)	3.7	102	5.6	16.2	12.8
Total Cadmium (mg/L)	0.009	0.107	<0.001	0.022	0.029
Total Lead (mg/L)	<0.05	0.13	<0.05	<0.05	<0.05
Mercury (mg/L)	0.00005	0.00005	0.00007	0.00005	0.00005

**Notes**

1. Results reported by Anaconda (1982) and Commercial Testing & Engineering Co. (1980) for samples and observations dated August 18, 1980.
2. Sample location described by Anaconda (1980) as "St. Louis Tunnel Discharge from the SE Drift."
3. Sample location described by Anaconda (1980) as "St. Louis Tunnel Discharge from the North Drift."
4. Sample location described by Anaconda (1980) as "St. Louis Tunnel Discharge from the 145 Raise Area."
5. Sample location described by Anaconda (1980) as "Total Discharge - St. Louis Portal."
6. Sample location described by Anaconda (1980) as "St. Louis adit discharge."
7. Flow proportions are "estimated portion of total flow" reported by Anaconda (1982).
8. All pH values reported by Commercial Testing & Engineering Co. (1980) were flagged with the following footnote, with the exception of the St. Louis Adit Discharge sample pH: "pH value may be low due to the possibility that the sample may have been preserved w/ acid."

**Abbreviations**

< = analyzed but not detected above the method reporting limit shown  
mg/L = milligram per liter  
NW = northwest  
SE = southeast



**TABLE 2-2**  
**OPTIMIZATION OF ST. LOUIS TUNNEL FLOW PROPORTIONS**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Parameter	Reported Flow Estimates and Analytical Results <sup>1</sup>				Projected SLT Discharge <sup>2</sup>	Ratio of Projected to Reported <sup>3</sup>	Optimized SLT Discharge <sup>4</sup>	Ratio of Optimized to Reported <sup>4</sup>	Relative Error <sup>4</sup>	Normalized Fractional Mass Loading <sup>5</sup>		
	SE Cross-cut	NW Cross-cut	145 Raise	SLT Discharge						SE Cross-cut	NW Cross-cut	145 Raise
Flow Fraction	67%	25%	8%	100%	100%	1.00	100%	1.00	0	82%	12%	6%
Fluoride (mg/L)	2.7	18	1.7	4.3	6.4	1.50	4.5	1.05	0.0022	49%	49%	2%
Sulfate (mg/L)	544	1070	505	562	670	1.19	610	1.09	0.0073	73%	22%	5%
Zinc, total (mg/L)	2.62	27	0.5	5.2	8.5	1.64	5.5	1.05	0.0025	39%	60%	1%
Iron, total (mg/L)	3.7	102	5.6	16.2	28	1.76	16	0.98	0.0006	19%	79%	2%
Cadmium, total (mg/L)	0.009	0.107	<0.001	0.022	0.033	1.49	0.020	0.93	0.0054	36%	64%	--
Lead, total (mg/L)	<0.05	0.13	<0.05	<0.05	--	--	--	--	--	--	--	--
Mercury (mg/L)	0.00005	0.00005	0.00007	0.00005	0.00005	1.03	0.00005	1.02	0.0006	80%	12%	8%
Optimized Flow Fraction <sup>4</sup>	<b>82%</b>	<b>12%</b>	<b>6%</b>	<b>Sum of Squared Errors: 0.019</b>								

#### **Notes**

1. Flow fractions and concentrations reported by Anaconda (1982) memorandum.
2. Concentrations calculated as the sum of flow fractions for tunnels contributing to the St. Louis Tunnel discharge multiplied with the reported concentrations.
3. Ratios calculated as the sum of mass inputs from the three contributing tunnels divided by mass output at the St. Louis Tunnel discharge. Ratios greater than 1.00 imply that either more mass is contributed by intersecting tunnels than is discharging from the St. Louis Tunnel or reported flow fractions are not accurate.
4. Flow fractions were optimized in order to approximate the St. Louis Tunnel discharge concentrations (based on mass inputs from the three contributing tunnels), targeting ratios of 1.00 for optimized to actual St. Louis Tunnel discharge concentrations and minimizing relative error.
5. Calculated as the mass input from each contributing tunnel, based on the optimized flow fraction, divided by the reported SLT discharge concentration.

#### **Abbreviations**

-- = not calculated due to lack of detected concentrations  
 % = percent  
 < = analyzed but not detected above the method reporting limit shown  
 mg/L = milligram per liter  
 SLT = St. Louis Tunnel

#### **References**

Anaconda, 1982. Water Quantity and Quality, St. Louis Tunnel: Rico. Internal correspondence from Jack Whyte to John Wilson, Anaconda Minerals Co.  
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**TABLE 2-3**  
**ANALYTICAL AND FIELD MONITORING RESULTS**  
**2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Sample:		Baseline, cofferdam	BLAINEIBF121004	BLAINEOBF121004	BLAINEIBF121016	BLAINEOBF121016	BLAINEIBF121031	BLAINEOBF121031	BLAINEIBF121114	BLAINEOBF121114	BLAINEIBF130430	BLAINEOBF130430
Date:		9/5/2012 17:47	10/4/2012 9:49	10/4/2012 9:39	10/16/2012 14:55	10/16/2012 14:50	10/31/2012 13:00	10/31/2012 12:55	11/14/2012 15:10	11/14/2012 15:05	04/30/2013 10:10	04/30/2013 10:00
Parameter	Units	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result
<b>Metals</b>												
Aluminum, Total	µg/L	268,000	NA	NA	NA	NA	NA	NA	NA	NA	199,000	248,000
Aluminum, Dissolved	µg/L	279,000	NA	NA	NA	NA	NA	NA	NA	NA	199,000	257,000
Antimony, Total	µg/L	<2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antimony, Dissolved	µg/L	<50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic, Total	µg/L	341	<200	3,060	44.3J	3,620	<1,000	4,890	30.0J	5,520	17.1 J	2,550
Arsenic, Dissolved	µg/L	364	62.8J	2,920	39.5J	3,460	<1,000	4,940	29.3J	5,410	19.5 J	2,630
Barium, Total	µg/L	<1.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barium, Dissolved	µg/L	<30.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Total	µg/L	27.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Dissolved	µg/L	27.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium, Total	µg/L	1,090	1,320	3,170	1,420	3,390	1,500	4,480	1,510	4,260	1,240	2,830
Cadmium, Dissolved	µg/L	1,540	1,320	2,950	1,420	3,350	1,520	4,530	1,520	4,180	1,220	2,860
Calcium, Total	µg/L	402,000	369,000	431,000	369,000	381,000	389,000	458,000	388,000	414,000	403,000	414,000
Calcium, Dissolved	µg/L	423,000	365,000	432,000	370,000	409,000	380,000	439,000	409,000	428,000	404,000	429,000
Chromium, Total	µg/L	233	221	294	230	240	212J	220J	154	268	171	173
Chromium, Dissolved	µg/L	238	267	295	228	232	186J	272J	150	265	169	185
Cobalt, Total	µg/L	237	235	495	236	452	235J	580J	196	528	170	290
Cobalt, Dissolved	µg/L	259	283	466	239	433	219J	576J	198	512	174	299
Copper, Total	µg/L	26,500	26,800	36,000	25,700	34,600	27,200	42,700	17,300	38,800	17,100	24,000
Copper, Dissolved	µg/L	26,600	26,700	33,700	25,500	32,700	26,600	43,900	16,600	37,800	17,600	24,800
Hardness, Total	mg/L	2,010	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Iron, Total	µg/L	1,870,000	1,600,000	2,910,000	1,550,000	2,740,000	1,690,000	4,280,000	1,130,000	3,890,000	1,020,000	2,180,000
Iron, Dissolved	µg/L	1,890,000	1,580,000	2,900,000	1,520,000	2,880,000	1,630,000	4,040,000	1,140,000	3,840,000	1,010,000	2,250,000
Lead, Total	µg/L	202	235	869	226	852	388J	400	388J	1,030	200	598
Lead, Dissolved	µg/L	244	270	916	225	829	389J	1,110	412	1,010	197	608
Lithium, Total	µg/L	383	NA	NA	NA	NA	NA	NA	NA	NA	247	317
Lithium, Dissolved	µg/L	350	284	369	262	362	285	480	288	450	249	338
Magnesium, Total	µg/L	245,000	215,000	249,000	223,000	235,000	222,000	287,000	231,000	270,000	213,000	228,000
Magnesium, Dissolved	µg/L	246,000	213,000	243,000	221,000	258,000	227,000	284,000	232,000	269,000	211,000	234,000
Manganese, Total	µg/L	113,000	112,000	172,000	114,000	220,000	112,000	216,000	112,000	212,000	91,400	129,000
Manganese, Dissolved	µg/L	107,000	108,000	162,000	115,000	214,000	513J	222,000	113,000	211,000	91,400	132,000
Mercury	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.20	<0.20
Mercury, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.20	<0.20
Molybdenum, Total	µg/L	9.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Molybdenum, Dissolved	µg/L	<50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel, Total	µg/L	398	430	574	426	530	513 J	644J	356	555	328	370
Nickel, Dissolved	µg/L	440	449	551	427	512	397 J	659J	360	542	342	376
Potassium, Total	µg/L	10,500	6,760J	<10,000	6,580	<5000	7,180	<2500	5,760	721J	563 J	<5000
Potassium, Dissolved	µg/L	11,300	5,980J	<10,000	7,350	1330J	7,980	<2500	5,270	1280J	769 J	519 J
Selenium, Total	µg/L	57.7	<200	<200	<100	49.5J	<1000	<1000	<100	64.5J	<100	<100
Selenium, Dissolved	µg/L	39.9	<200	<200	<100	45.1J	<1000	<1000	<100	60.4J	<100	<100
Silica, Total	µg/L	109,000	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silica, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver, Total	µg/L	<2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver, Dissolved	µg/L	<50.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

**TABLE 2-3**  
**ANALYTICAL AND FIELD MONITORING RESULTS**  
**2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Sample:		Baseline, cofferdam	BLAINEIBF121004	BLAINEOBF121004	BLAINEIBF121016	BLAINEOBF121016	BLAINEIBF121031	BLAINEOBF121031	BLAINEIBF121114	BLAINEOBF121114	BLAINEIBF130430	BLAINEOBF130430
Date:		9/5/2012 17:47	10/4/2012 9:49	10/4/2012 9:39	10/16/2012 14:55	10/16/2012 14:50	10/31/2012 13:00	10/31/2012 12:55	11/14/2012 15:10	11/14/2012 15:05	04/30/2013 10:10	04/30/2013 10:00
Parameter	Units	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result
Sodium, Total	µg/L	6,580	5420J	20,400	5,500	21,700	5,960	26,300	5,320	29,100	4390 J	12,200
Sodium, Dissolved	µg/L	6,940	5520J	19,700	5,330	23,700	34,400	25,900	4340J	28,000	4450 J	12,800
Thallium, Total	µg/L	2.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thallium, Dissolved	µg/L	<10.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Total	µg/L	334	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Dissolved	µg/L	342	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc, Total	µg/L	228,000	202,000	479,000	216,000	575,000	220,000	623,000	266,000	644,000	183,000	444,000
Zinc, Dissolved	µg/L	226,000	199,000	451,000	217,000	555,000	NA	637,000	270,000	632,000	182,000	436,000
<b>General Water Chemistry and Anions</b>												
Alkalinity, Bicarbonate	mg/L as CaCO <sub>3</sub>	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	261	<20.0	<20.0	<20.0
Alkalinity, Carbonate	mg/L as CaCO <sub>3</sub>	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
Alkalinity, Hydroxide	mg/L as CaCO <sub>3</sub>	NA	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0
Alkalinity, Total	mg/L as CaCO <sub>3</sub>	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	<20.0	261	<20.0	<20.0	<20.0
Total Dissolved Solids	mg/L	2,740	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Suspended Solids	mg/L	7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulfide, Total	mg/L	<0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bromide	mg/L	<1.0	<1.0	<1.0	1.2	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Chloride	mg/L	3.2	1.3	2.0	4.1	2.2	2.2	9.7	1.2	5.8	2.3	<1.0
Fluoride	mg/L	77.1	63.6	47.5	60.2	42.8	53.3	46.3	47.7	50.0	42.3	33.5
Sulfate	mg/L	59,500	13,500	23,400	26,100	27,700	222,000	40,400	23,400	72,400	15,800	23,500
Nitrogen, Nitrate	mg/L	<0.50	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Organic Carbon	mg/L	4.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
<b>Field Monitoring Parameters</b>												
pH	standard units	2.2	2.39	2.14	2.58	2.15	2.41	2.2	2.47	2.03	2.53	2.05
Temperature	°C	13.57	9.58	10.7	7.38	7.62	10.75	9.2	3.11	0.46	14.19	10.8
Conductivity	µS/cm	7,703	5,237	8,071	4,975	7,851	5,435	9,657	3,921	7,120	6,010	10,033
Dissolved Oxygen	mg/L	0.83	11.57	10.03	NM	NA	8.21	3.91	9.26	7.4	1.46	1.17
Oxidation Reduction Potential	mV	449.8	285.7	303.5	386	398	381.8	395.4	303.6	301.2	491.1	504

**Notes**

- DR-3 data provided by Anderson Engineering Company. Only DR-3 data used to perform mass loading calculations was included herein.
- Preliminary data set.

**Abbreviations:**

°C = degrees Celsius  
 < = analyzed but not detected above the method reporting limit shown  
 CaCO<sub>3</sub> = calcium carbonate  
 J = result is above method detection limit but below reporting limit  
 mg/L = milligram per liter  
 mV = millivolt  
 NA = not analyzed  
 µg/L = microgram per liter  
 µS/cm = microSiemen per centimeter

**TABLE 2-3**  
**ANALYTICAL AND FIELD MONITORING RESULTS**  
**2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Sample:	BLAINEIBF	BLAINEOBF SEEP	BLAINEIBF TRANSDUCER	BLAINEIBF130619	BLAINEOBF130619	BLAINEIBF130709	BLAINEOBF130709	BLAINEIBF130821	BLAINEOBF130821	BLAINEIBF130924	BLAINEOBF130924	
Date:	5/17/2013 14:50	5/17/2013 14:55	5/17/2013 15:00	6/19/2013	6/19/2013	7/9/2013	7/9/2013	8/21/2013	8/21/2013	9/24/2013	9/24/2013	
Parameter	Units	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	
Metals												
Aluminum, Total	µg/L	NA	NA	NA	280,000	322,000	258,000	255,000	235,000	227,000	241,000	257,000
Aluminum, Dissolved	µg/L	NA	NA	NA	256,000	301,000	255,000	251,000	234,000	229,000	249,000	276,000
Antimony, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Antimony, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic, Total	µg/L	NA	NA	NA	35.4	648	38.6	608	41.7	704	47.9J	1,230
Arsenic, Dissolved	µg/L	NA	NA	NA	34.8	597	39.5	608	40.8	679	51.5J	1,690
Barium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Barium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Beryllium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium, Total	µg/L	NA	NA	NA	1,530	1,890	1,320	1,610	1,570	1,780	1,400	1,800
Cadmium, Dissolved	µg/L	NA	NA	NA	1,480	2,010	1,340	1,610	1,490	1,740	1,370	2,220
Calcium, Total	µg/L	NA	NA	NA	387,000	408,000	379,000	388,000	357,000	350,000	387,000	401,000
Calcium, Dissolved	µg/L	NA	NA	NA	401,000	427,000	373,000	379,000	358,000	350,000	390,000	399,000
Chromium, Total	µg/L	NA	NA	NA	183	252	216	211	227	221	224	235
Chromium, Dissolved	µg/L	NA	NA	NA	177	196	223	212	207	213	214	242
Cobalt, Total	µg/L	NA	NA	NA	181	288	220	246	238	258	263	300
Cobalt, Dissolved	µg/L	NA	NA	NA	174	212	226	248	215	239	258	346
Copper, Total	µg/L	NA	NA	NA	26,600	29,200	26,000	26,800	23,300	23,700	26,400	28,900
Copper, Dissolved	µg/L	NA	NA	NA	26,600	30,900	25,200	25,000	21,200	22,600	25,800	30,200
Hardness, Total	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Iron, Total	µg/L	NA	NA	NA	1,590,000	2,010,000	1,490,000	1,640,000	1,260,000	1,420,000	1,440,000	1,920,000
Iron, Dissolved	µg/L	NA	NA	NA	1,830,000	2,400,000	1,460,000	1,600,000	1,330,000	1,420,000	1,470,000	2,240,000
Lead, Total	µg/L	NA	NA	NA	184	218	163	201	168	240	219	1,820
Lead, Dissolved	µg/L	NA	NA	NA	176	215	164	201	163	235	214	432
Lithium, Total	µg/L	NA	NA	NA	345	389	288	302	271	261	268	304
Lithium, Dissolved	µg/L	NA	NA	NA	273	328	286	288	265	271	275	358
Magnesium, Total	µg/L	NA	NA	NA	254,000	259,000	221,000	220,000	200,000	201,000	192,000	199,000
Magnesium, Dissolved	µg/L	NA	NA	NA	244,000	262,000	219,000	215,000	197,000	197,000	189,000	212,000
Manganese, Total	µg/L	NA	NA	NA	101,000	114,000	97,000	105,000	102,000	104,000	99,200	106,000
Manganese, Dissolved	µg/L	NA	NA	NA	100,000	119,000	97,800	103,000	98,000	106,000	95,000	115,000
Mercury	µg/L	NA	NA	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.24
Mercury, Dissolved	µg/L	NA	NA	NA	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Molybdenum, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Molybdenum, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel, Total	µg/L	NA	NA	NA	298	395	374	378	399	402	444	460
Nickel, Dissolved	µg/L	NA	NA	NA	289	316	388	380	362	371	418	440
Potassium, Total	µg/L	NA	NA	NA	4640J	3700J	3,320	2,690	2,620	2,010	10,700	10,500
Potassium, Dissolved	µg/L	NA	NA	NA	3,940	3,320	3,200	2,580	2,680	2,020	11,600	9,320
Selenium, Total	µg/L	NA	NA	NA	21.8	32.2J	22.4	29.4	26.9	37	25.0J	32.9J
Selenium, Dissolved	µg/L	NA	NA	NA	20	29.1	23.8	29.6	29.5	33.7	21.7J	30.5J
Silica, Total	µg/L	NA	NA	NA	44,700	52,000	42,500	43,800	41,400	41,300	43,200	47,400
Silica, Dissolved	µg/L	NA	NA	NA	43,900	52,400	41,600	42,600	40,600	41,000	44,200	48,800
Silver, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Silver, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

**TABLE 2-3**  
**ANALYTICAL AND FIELD MONITORING RESULTS**  
**2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Sample:		BLAINEIBF	BLAINEOBF SEEP	BLAINEIBF TRANSDUCER	BLAINEIBF130619	BLAINEOBF130619	BLAINEIBF130709	BLAINEOBF130709	BLAINEIBF130821	BLAINEOBF130821	BLAINEIBF130924	BLAINEOBF130924
Date:		5/17/2013 14:50	5/17/2013 14:55	5/17/2013 15:00	6/19/2013	6/19/2013	7/9/2013	7/9/2013	8/21/2013	8/21/2013	9/24/2013	9/24/2013
Parameter	Units	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result	Result
Sodium, Total	µg/L	NA	NA	NA	4910J	6,590	4,270	8,720	4,120	4,490	4,340	4,710
Sodium, Dissolved	µg/L	NA	NA	NA	4400J	6,360	4,140	8,550	4,130	4,550	4,550	4,930
Thallium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thallium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Total	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium, Dissolved	µg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc, Total	µg/L	NA	NA	NA	233,000	289,000	197,000	231,000	177,000	198,000	184,000	226,000
Zinc, Dissolved	µg/L	NA	NA	NA	226,000	288,000	200,000	231,000	174,000	196,000	177,000	293,000
<b>General Water Chemistry and Anions</b>												
Alkalinity, Bicarbonate	mg/L as CaCO <sub>3</sub>	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Alkalinity, Carbonate	mg/L as CaCO <sub>3</sub>	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Alkalinity, Hydroxide	mg/L as CaCO <sub>3</sub>	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Alkalinity, Total	mg/L as CaCO <sub>3</sub>	NA	NA	NA	<20	<20	<40	<40	<20	<20	<20	<20
Total Dissolved Solids	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Suspended Solids	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Sulfide, Total	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Bromide	mg/L	NA	NA	NA	<1	<1	<1	<1	<1	<1	<1	<1
Chloride	mg/L	NA	NA	NA	2	<1	1.8	2.5	1.4	1.6	1.9	0.70J
Fluoride	mg/L	NA	NA	NA	81.9	77.8	92.5	85.8	110	59.5	77.3	72.6
Sulfate	mg/L	NA	NA	NA	23,100	20,600	36,200	18,500	11,700	24,400	11,000	28,900
Nitrogen, Nitrate	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Organic Carbon	mg/L	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
<b>Field Monitoring Parameters</b>												
pH	standard units	2.28	1.87	1.85	2.4	2.3	2.42	2.34	2.47	2.37	2.34	2.20
Temperature	°C	9.65	5.81	5.25	15.36	10.34	14.32	14.99	10.61	12.54	10.81	10.78
Conductivity	µS/cm	7,706	12,587	12,657	7,443	8,542	7,040	7,466	6,708	7,308	7,163	9,060
Dissolved Oxygen	mg/L	1.75	1.89	1.68	3.02	3.67	3.85	2.96	3.08	4.33	5.91	6.58
Oxidation Reduction Potential	mV	468.5	485.6	485.4	468	469	447.9	425.1	489.7	498	469.2	475.7

**Notes**

- DR-3 data provided by Anderson Engineering Company. Only DR-3 data used to perform mass loading calculations was included herein.
- Preliminary data set.

**Abbreviations:**

°C = degrees Celsius  
 < = analyzed but not detected above the method reporting limit shown  
 CaCO<sub>3</sub> = calcium carbonate  
 J = result is above method detection limit but below reporting limit  
 mg/L = milligram per liter  
 mV = millivolt  
 NA = not analyzed  
 µg/L = microgram per liter  
 µS/cm = microSiemen per centimeter

**TABLE 2-3**  
**ANALYTICAL AND FIELD MONITORING RESULTS**  
**2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Sample:		DR-3_20130425	DR-3_20130612	DR-3_20130710	DR-3_20130827
Date:		4/25/2013	6/12/2013	7/10/2013	8/27/2013
Parameter	Units	Result <sup>1</sup>	Result <sup>1</sup>	Result <sup>1</sup>	Result <sup>1,2</sup>
<b>Metals</b>					
Aluminum, Total	µg/L	1,020	901	372	822
Aluminum, Dissolved	µg/L	51.2	30.4	23.0	20.6
Antimony, Total	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Antimony, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Arsenic, Total	µg/L	2.4	1.8	0.70	1.5
Arsenic, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Barium, Total	µg/L	22.7	21.7	18.9	21.9
Barium, Dissolved	µg/L	20.2	21.0	20.3	19.9
Beryllium, Total	µg/L	1.1	1.1	0.56	0.85
Beryllium, Dissolved	µg/L	0.33	0.32	0.34	0.31
Cadmium, Total	µg/L	19.0	24.1	18.1	21.1
Cadmium, Dissolved	µg/L	15.4	20.5	19.2	18.9
Calcium, Total	µg/L	293,000	243,000	311,000	263,000
Calcium, Dissolved	µg/L	257,000	239,000	229,000	256,000
Chromium, Total	µg/L	0.57	0.54	< 0.50	<0.50
Chromium, Dissolved	µg/L	0.70	0.56	< 0.50	<0.50
Cobalt, Total	µg/L	3.2	2.9	2.5	2.8
Cobalt, Dissolved	µg/L	2.8	2.8	2.7	2.7
Copper, Total	µg/L	170	184	80.2	179
Copper, Dissolved	µg/L	12.9	9.1	8.6	8.1
Hardness, Total	mg/L	811	688	849	741
Iron, Total	µg/L	12,400	9,040	4,600	8,380
Iron, Dissolved	µg/L	1,420	285	428	315
Lead, Total	µg/L	25.0	17.0	5.7	15.6
Lead, Dissolved	µg/L	1	0.25	< 0.10	<0.10
Lithium, Total	µg/L	NA	NA	NA	NA
Lithium, Dissolved	µg/L	NA	NA	NA	NA
Magnesium, Total	µg/L	19,600	19,800	17,600	20,500
Magnesium, Dissolved	µg/L	19,100	19,500	18,700	20,400
Manganese, Total	µg/L	1,890	1,930	2,170	1,910
Manganese, Dissolved	µg/L	1,760	1,860	1,820	1,820
Mercury	µg/L	< 0.20	< 0.20	< 0.20	<0.20
Mercury, Dissolved	µg/L	< 0.20	< 0.20	< 0.20	<0.20
Molybdenum, Total	µg/L	17.4	16.4	17.8	17.4
Molybdenum, Dissolved	µg/L	14.6	13.8	18.6	14.9
Nickel, Total	µg/L	4.0	4.6	3.9	4.2
Nickel, Dissolved	µg/L	7.8	4.8	4.7	6.0
Potassium, Total	µg/L	5,420	4,020	3,660	3,330
Potassium, Dissolved	µg/L	5,360	3,970	3,480	3,280
Selenium, Total	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Selenium, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Silica, Total	µg/L	20,500	19,600	20,100	19,500
Silica, Dissolved	µg/L	NA	NA	NA	NA
Silver, Total	µg/L	< 0.50	< 0.50	< 0.50	<0.50
Silver, Dissolved	µg/L	< 0.50	< 0.50	< 0.50	<0.50



**TABLE 2-3**  
**ANALYTICAL AND FIELD MONITORING RESULTS**  
**2012-2013 BLAINE TUNNEL AND SELECTED DR-3 WATER SAMPLES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Sample: Date:		DR-3_20130425 4/25/2013	DR-3_20130612 6/12/2013	DR-3_20130710 7/10/2013	DR-3_20130827 8/27/2013
Parameter	Units	Result <sup>1</sup>	Result <sup>1</sup>	Result <sup>1</sup>	Result <sup>1,2</sup>
Sodium, Total	µg/L	14,000	11,600	26,800	14,300
Sodium, Dissolved	µg/L	11,800	11,300	22,600	14,900
Thallium, Total	µg/L	< 0.10	< 0.10	< 0.10	<0.10
Thallium, Dissolved	µg/L	< 0.10	< 0.10	< 0.10	<0.10
Vanadium, Total	µg/L	0.21	0.17	< 0.10	0.18
Vanadium, Dissolved	µg/L	< 0.10	< 0.10	< 0.10	<0.10
Zinc, Total	µg/L	4,050	4,620	4,220	4,080
Zinc, Dissolved	µg/L	3,230	3,930	3,620	3,640
<b>General Water Chemistry and Anions</b>					
Alkalinity, Bicarbonate	mg/L as CaCO <sub>3</sub>	95.0	90.8	95.9	144
Alkalinity, Carbonate	mg/L as CaCO <sub>3</sub>	< 20.0	< 20.0	< 20.0	< 20.0
Alkalinity, Hydroxide	mg/L as CaCO <sub>3</sub>	NA	NA	NA	NA
Alkalinity, Total	mg/L as CaCO <sub>3</sub>	95.0	90.8	95.9	144
Total Dissolved Solids	mg/L	920	980	988	1,110
Total Suspended Solids	mg/L	19.0	29.0	15.0	22.0
Sulfide, Total	mg/L	< 0.050	< 0.050	< 0.050	< 0.050
Bromide	mg/L	NA	NA	NA	NA
Chloride	mg/L	< 1.0	< 1.0	< 1.0	1.4
Fluoride	mg/L	NA	NA	NA	NA
Sulfate	mg/L	687	774	660	604
Nitrogen, Nitrate	mg/L	< 0.10	< 0.10	< 0.10	0.13
Total Organic Carbon	mg/L	< 1.0	< 0.50	< 0.50	< 0.50
<b>Field Monitoring Parameters</b>					
pH	standard units	7.13	6.89	7.15	6.54
Temperature	°C	16.98	20.08	20.02	6.55
Conductivity	µS/cm	1,422	1,474	1,466	1,342
Dissolved Oxygen	mg/L	1.59	5.8	2.97	5.29
Oxidation Reduction Potential	mV	-47.1	-11.7	-37.9	-22.3

**Notes**

- DR-3 data provided by Anderson Engineering Company. Only DR-3 data used to perform mass loading calculations was included herein.
- Preliminary data set.

**Abbreviations:**

°C = degrees Celsius  
 < = analyzed but not detected above the method reporting limit shown  
 CaCO<sub>3</sub> = calcium carbonate  
 J = result is above method detection limit but below reporting limit  
 mg/L = milligram per liter  
 mV = millivolt  
 NA = not analyzed  
 µg/L = microgram per liter  
 µS/cm = microSiemen per centimeter

**TABLE 2-4**  
**COMPARISON OF BLAINE TUNNEL AND ST. LOUIS TUNNEL**  
**CONTAMINANT DISCHARGE RATES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Location	Loading Rates		Blaine Loading Contribution <sup>5</sup>	Loading Rates		Blaine Loading Contribution <sup>5</sup>	Loading Rates		Blaine Loading Contribution <sup>5</sup>	Loading Rates		Blaine Loading Contribution <sup>5</sup>	Loading Rate Blaine <sup>3</sup>
	Blaine <sup>3</sup>	DR-3 <sup>4</sup>		Blaine <sup>3</sup>	DR-3 <sup>4</sup>		Blaine <sup>3</sup>	DR-3 <sup>4</sup>		Blaine <sup>3</sup>	DR-3 <sup>4</sup>		
Sample Date	4/30/2013	4/25/2013	April 2013	6/19/2013	6/12/2013	June 2013	7/9/2013	7/10/2013	July 2013	8/21/2013	8/27/2013	August 2013	Peak <sup>6</sup>
Flow Rate <sup>1,2</sup> (gpm)	0.03	498	Estimated Range	0.11	543	Estimated Range	0.13	509	Estimated Range	0.32	539	Estimated Range	3.0
Analyte	(g/d)	(g/d)	lower upper	(g/d)	(g/d)	lower upper	(g/d)	(g/d)	lower upper	(g/d)	(g/d)	lower upper	(g/d)
Arsenic, Total	0.4 - 0.8	6.5	6% - 12%	0.4 - 0.8	5.3	7% - 15%	0.4 - 0.9	1.9	21% - 46%	1.2 - 2.5	4.4	27% - 57%	40 - 80
Arsenic, Dissolved <sup>7</sup>	0.4 - 0.8	1.4	29% - 59%	0.4 - 0.7	1.5	27% - 47%	0.4 - 0.9	1.4	29% - 65%	1.2 - 2.4	1.5	82% - 163%	40 - 90
Cadmium, Total	0.4 - 0.8	52	0.8% - 2%	1.2 - 2.3	71	2% - 3%	1.1 - 2.3	50	2% - 5%	3.1 - 6.2	62	5% - 10%	50 - 90
Cadmium, Dissolved	0.4 - 0.9	42	1% - 2%	1.2 - 2.5	61	2% - 4%	1.1 - 2.3	53	2% - 4%	3 - 6.1	56	5% - 11%	50 - 90
Iron, Total	330 - 650	33,700	1% - 2%	1200 - 2500	26,800	4% - 9%	1200 - 2300	12,800	9% - 18%	2500 - 5000	24,600	10% - 20%	36000 - 71000
Iron, Dissolved	340 - 670	3,860	9% - 17%	1500 - 3000	845	178% - 355%	1100 - 2300	1,190	92% - 193%	2500 - 5000	926	270% - 540%	37000 - 74000
Manganese, Total	20 - 40	5,140	0.4% - 1%	70 - 140	5,510	1% - 3%	70 - 150	6,020	1% - 2%	180 - 360	5,610	3% - 6%	2100 - 4200
Manganese, Dissolved	20 - 40	4,790	0.4% - 1%	70 - 150	5,720	1% - 3%	70 - 150	5,050	1% - 3%	190 - 370	5,350	4% - 7%	2200 - 4300
Zinc, Total	70 - 130	11,000	1% - 1%	180 - 360	11,600	2% - 3%	160 - 330	11,700	1% - 3%	350 - 690	12,000	3% - 6%	7300 - 15000
Zinc, Dissolved	70 - 130	8,780	1% - 1%	180 - 350	13,700	1% - 3%	160 - 330	10,000	2% - 3%	340 - 680	10,700	3% - 6%	7100 - 14000

**Notes:**

1. Flume flow rates were determined from depths measured by an ultrasonic sensor positioned above a flume. Flume average flow rates were calculated by averaging the hourly flow rates for the 24-hour period on which the sampling event occurred.
2. Average flow rate for the date that samples were collected, based on data reported by AECL. Flume average flow rates were calculated by averaging the flow rates recorded every 15 minutes for the date on which the sampling event occurred.
3. Blaine mass loading rate estimates assumed that all flow to the Humboldt Drift passed through the Blaine flume (lower-end of the range) or was added by the inflow immediately out-by (down-gradient) of the flume (upper-end of the range). Mass loading rates for the lower-end of the range were determined by multiplying the analyte concentration measured out-by of the flume during a sampling event with the flume average flow rate for the corresponding date. Upper-end values were determined by multiplying the analyte concentration measured out-by of the flume with two times the flume average flow rate. The upper-end values reflect maximum mass loading estimates, assuming that the flow rate for the inflow located out-by of the flume equals the flume flow rate.
4. St. Louis Tunnel mass loading rate estimates are equal to the product of the average flow rate and the reported concentration for samples collected from the DR-3 or DR-3A sampling location, immediately downstream of the St. Louis Tunnel portal.
5. Blaine loading contribution to the St. Louis Tunnel discharge was estimated by dividing Blaine mass loading rates by DR-3 mass loading rates.
6. Peak mass loading rates were estimated based on maximum detected flow rates and analyte concentrations. Peak flow through the flume was recorded on January 18, 2013; peak concentrations for the analytes presented herein corresponded to the April 30, 2013, sampling event.
7. Loading calculations are based on the laboratory reporting limit for this analyte; analyte was not detected in samples from DR-3 above the reporting limit.

**Abbreviations:**

gpm = gallon per minute  
g/d = gram per day

**TABLE 4-1**  
**FLOW AND CONTAMINANT LOADING CONTRIBUTIONS**  
**AND SOLIDS GENERATION ESTIMATES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

Parameter	St. Louis Tunnel Discharge at DR-3 <sup>1</sup>					SE Cross-cut <sup>3</sup>					Combined NW Cross-cut and 145 Raise <sup>4</sup>					517 Shaft Treatment Scenario <sup>5</sup>	
	Concentration (µg/L)	Flow Rate (gpm)	Metals Loading Rate <sup>2</sup> (lb/day)	Sludge Production Rate <sup>2</sup> (lb/day)	Percent of Total Sludge <sup>2</sup>	Concentration (µg/L)	Estimated Flow Rate (gpm)	Metals Loading Rate <sup>2</sup> (lb/day)	Percent of DR-3 Metals Loading	Sludge Production Rate <sup>2</sup> (lb/day)	Estimated Concentration (µg/L)	Estimated Flow Rate (gpm)	Metals Loading Rate <sup>2</sup> (lb/day)	Percent of DR-3 Metals Loading	Sludge Production Rate <sup>2</sup> (lb/day)	DR- 3 Concentration (µg/L)	Percent Reduction at DR-3 (by Parameter)
Aluminum	956	530	6.1	13.8	0.3%	76.4	353	0.32	5%	0.7	2,715	177	5.8	95%	13.0	905	5.3%
Cadmium	23.4	530	0.15	0.19	0.0%	9.4	353	0.040	27%	0.05	51.4	177	0.11	73%	0.14	17.1	27%
Calcium	245,000	530	1,600	4,000	89.3%	312,000	353	1,320	83%	3,300	128,625	177	270	18%	675	42,875	83%
Copper	194	530	1.2	1.9	0.0%	16.1	353	0.068	6%	0.1	549.8	177	1.2	94%	1.8	183	5.5%
Iron	8,490	530	54	86	1.9%	719	353	3.1	6%	5	24,032	177	51	94%	81	8,011	5.6%
Magnesium	20,300	530	130	312	7.0%	26,300	353	110	85%	264	9,369	177	20	15%	48	3,123	85%
Manganese	1,840	530	12	24	0.5%	1,170	353	5.0	42%	10	3,180	177	6.7	58%	14	1,060	42%
Zinc	4,340	530	28	42	1%	2,990	353	13	46%	19	7,040	177	15	54%	23	2,347	46%
<b>Totals (lbs/d)</b>			<b>1,831</b>	<b>4,480</b>		<b>SE Cross-cut (lbs/d)</b>		<b>1,451</b>		<b>3,599</b>	<b>NW Cross-cut (lbs/d)</b>		<b>370</b>		<b>856</b>		

**Notes**

- DR-3 concentrations are from sample DR3A130619, collected on June 19, 2013, at monitoring location DR-3A. The DR-3 flow rate was measured manually on June 12, 2013.
- Metals loading rate is the product of flow and concentration. Sludge production rate assumes full precipitation of analytes as solids.
- SE Cross-cut concentrations are from sample 517SHAFT465130619, collected on June 19, 2013, from the 517 Shaft. Flow rate assumes that 67% of DR-3 flow originates from the SE cross-cut, per Anaconda (1982).
- NW Cross-cut concentrations are calculated based on DR-3 and SE Cross-cut concentrations, assuming that 33% of DR-3 flow originates from the NW Cross-cut and 145 Raise, per Anaconda (1982), and the balance of mass loading not originating from the SE Cross-cut is contributed by the combined flow from the NW Cross-cut and 145 Raise.
- This scenario assumes full removal of metals concentrations from the SE Cross-cut by treatment at the 517 Shaft. Predicted DR-3 concentrations were calculated by dividing the estimated mass load from the combined NW Cross-cut and 145 Raise by the flow rate at DR-3.

**Abbreviations**

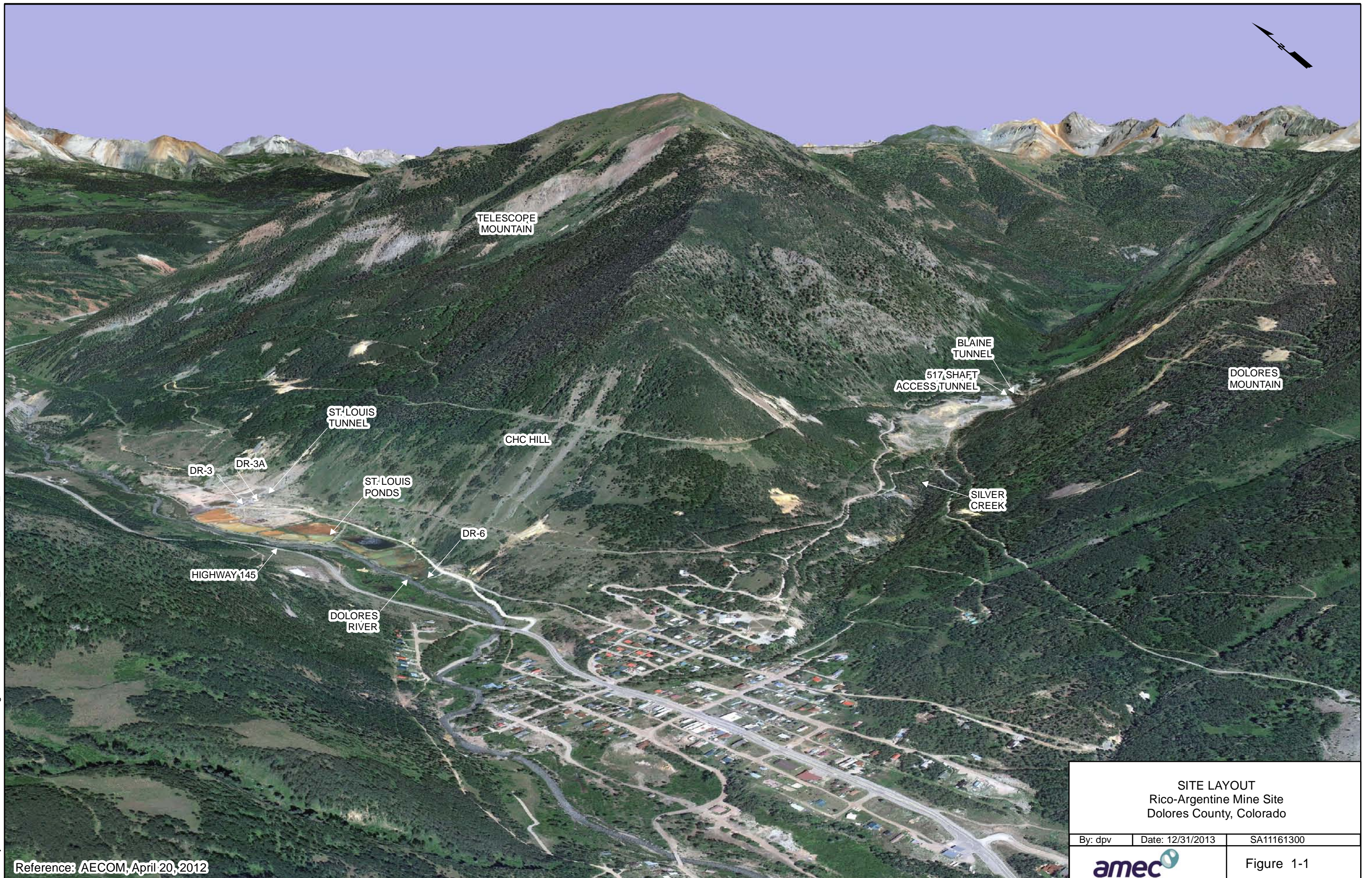
% = percent  
gpm = gallon per minute  
lbs/d = pound per day  
µg/L = microgram per liter

## FIGURES

---



P:\Project\160000s\SA1116\1300 - Rico-Argentine Mine Site\14000 CAD\Blaine Tunnel2\_Rico Mine Site.mxd



Reference: AECOM, April 20, 2012

SITE LAYOUT  
Rico-Argentine Mine Site  
Dolores County, Colorado

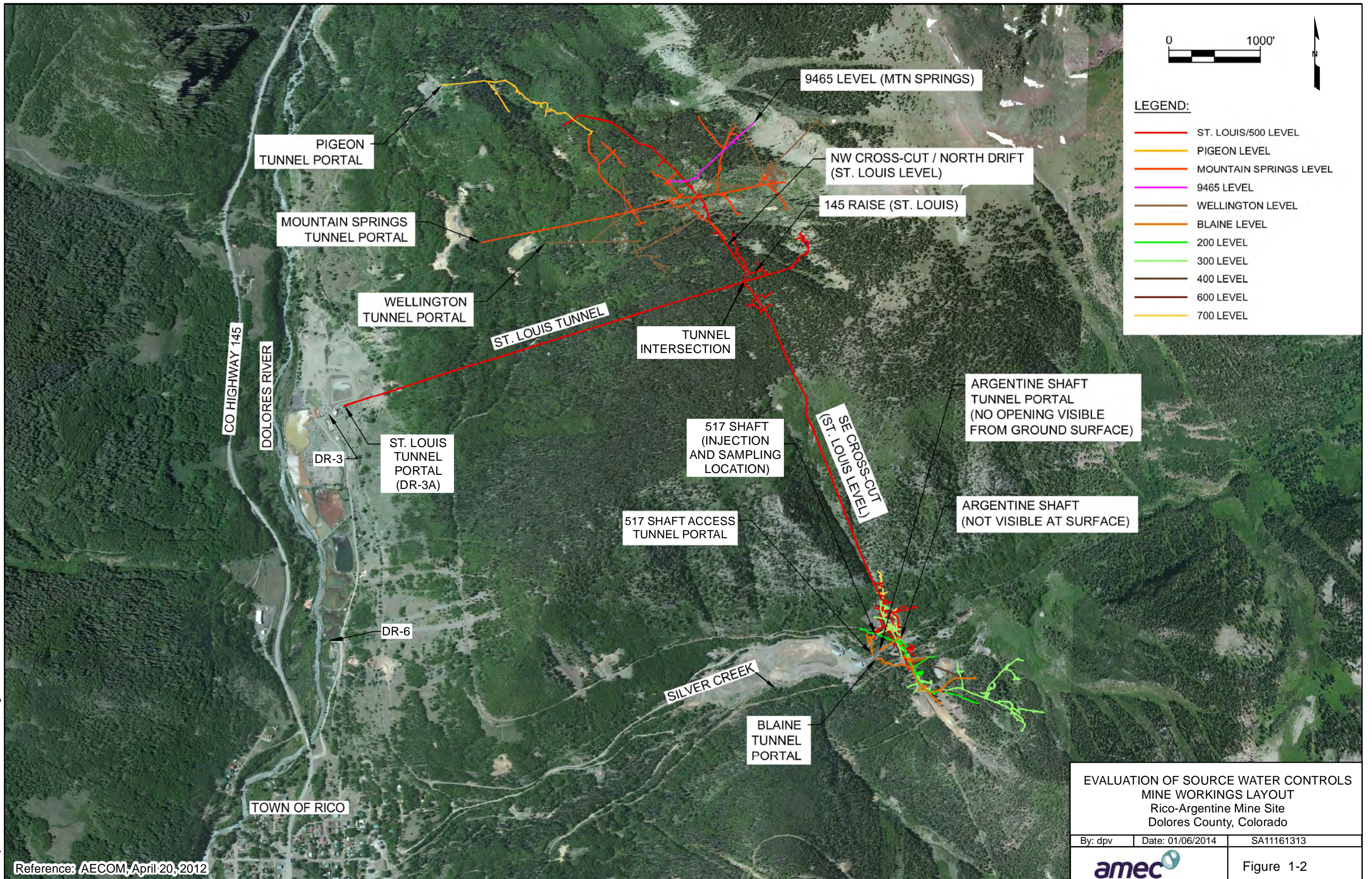
By: dpv	Date: 12/31/2013	SA11161300
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Figure 1-1

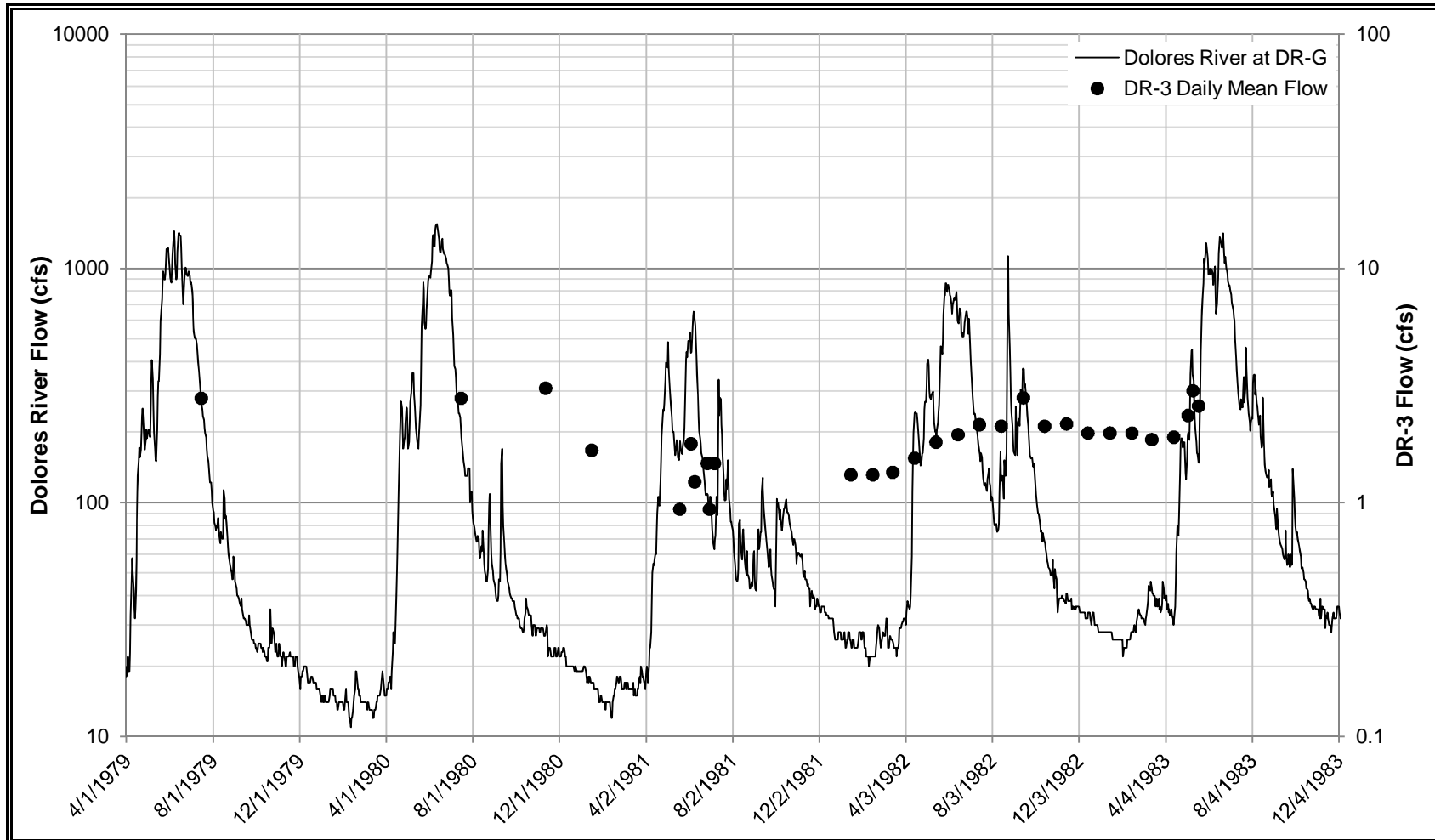


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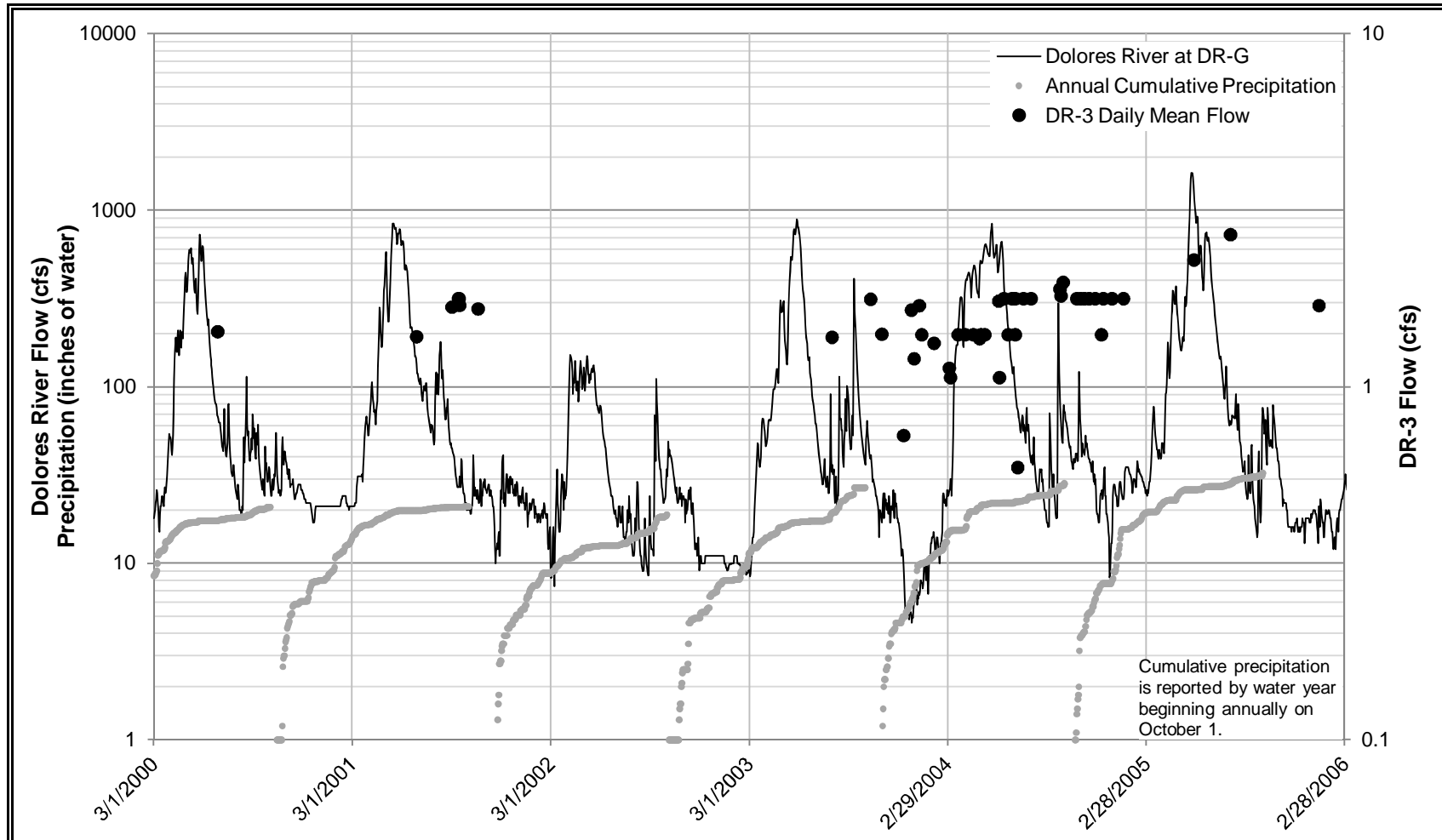




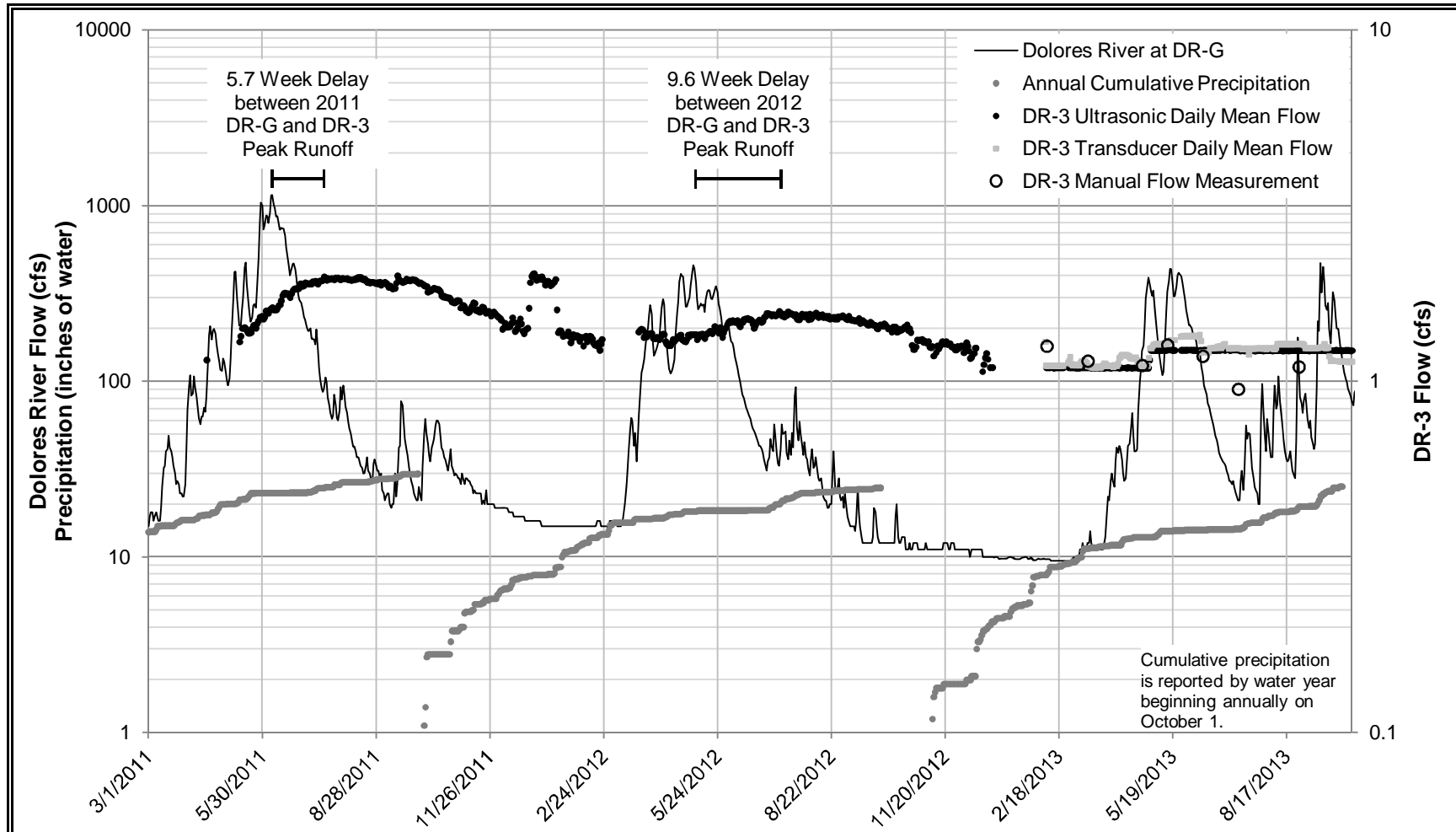
**FIGURE 2-1**  
**1979-1983 FLOW RATES**  
**ST. LOUIS TUNNEL DISCHARGE AND DOLORES RIVER**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



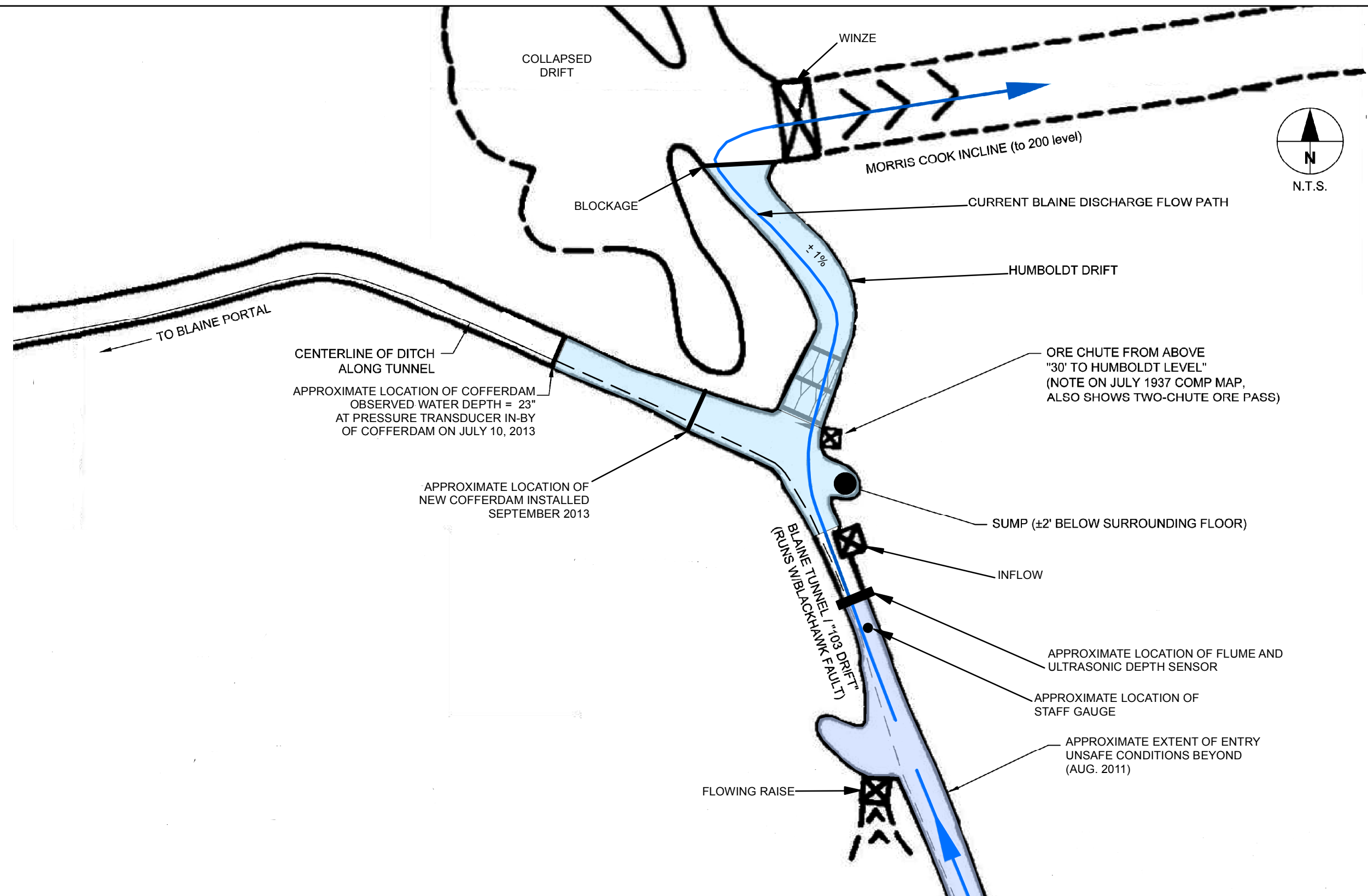
**FIGURE 2-2**  
**2000-2006 FLOW RATES**  
**ST. LOUIS TUNNEL DISCHARGE AND DOLORES RIVER**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



**FIGURE 2-3**  
**2011-2013 FLOW RATES**  
**ST. LOUIS TUNNEL DISCHARGE AND DOLORES RIVER**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



P:\Project\160000s\SA1116\1300 - Rico-Argentine Mine Site\14000\_CAD\Blaine Tunnel\Blaine\_TunnelMap.mxd



BACKGROUND IMAGE SOURCE:  
"BLAINE LEVEL... TAKEN FROM TUCK MAP, 1959"  
DOCUMENT NUMBER CTRL0009629

BLAINE TUNNEL DETAILS SOURCE:  
ATLANTIC RICHFIELD, 2013, BLAINE BASE FLOW MEASUREMENT WORK PLAN, RICO-ARGENTINE MINE  
SITE - RICO TUNNELS OPERABLE UNIT OU01, RICO, COLORADO, PREPARED BY AECOM, MARCH.

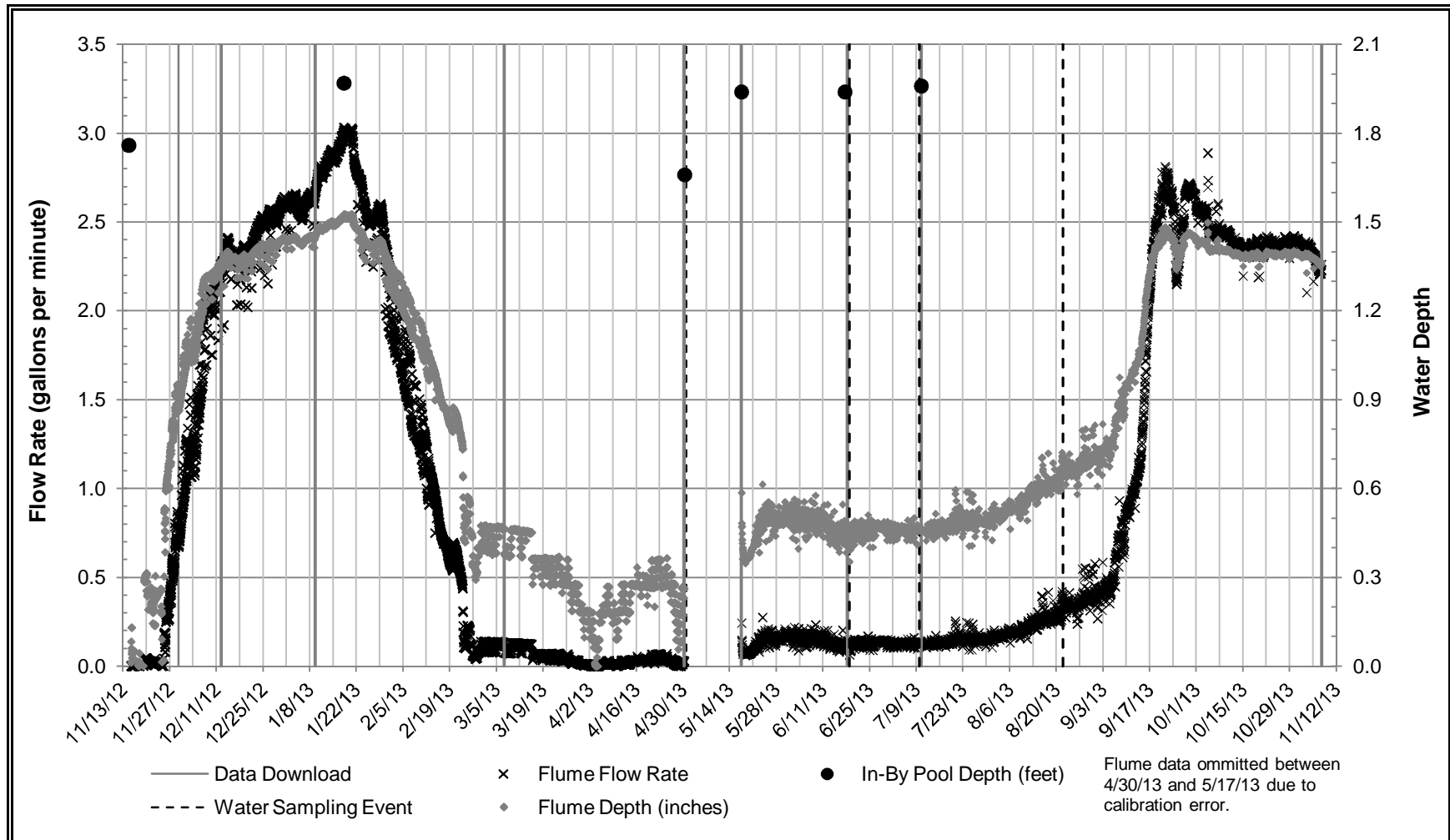
BLAINE TUNNEL LAYOUT  
EVALUATION OF SOURCE WATER CONTROLS  
Rico-Argentine Mine Site  
Dolores County, Colorado

By: DPV	Date: 12/31/2013	Project No. SA11161300
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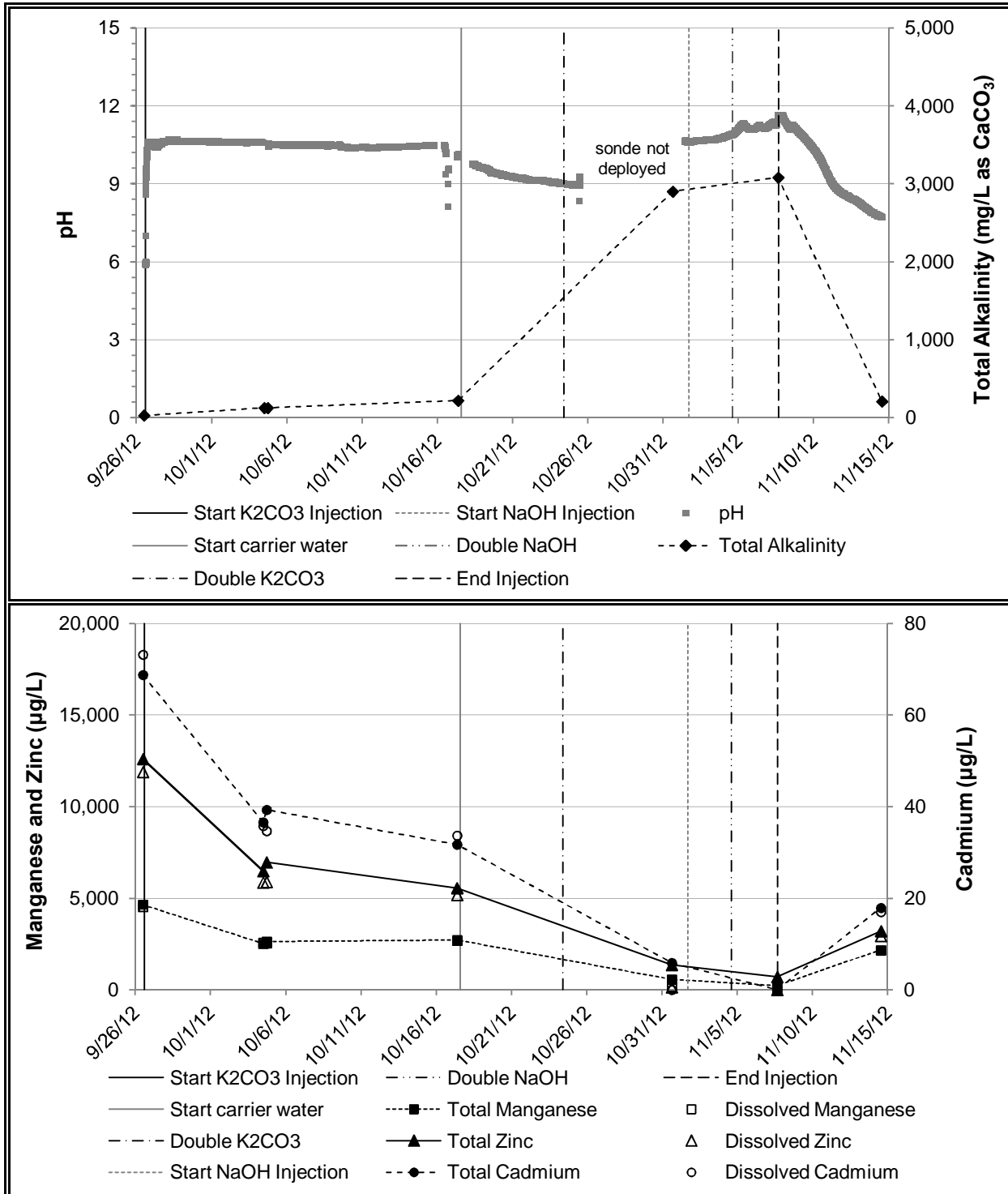


Figure 2-4

**FIGURE 2-5**  
**BLAINE TUNNEL FLUME ULTRASONIC SENSOR**  
**FLOW RATE AND WATER DEPTH: 2012-2013**  
**EVALUATION OF SOURCE WATER CONTROLS**  
 Rico-Argentine Mine Site  
 Dolores County, Colorado

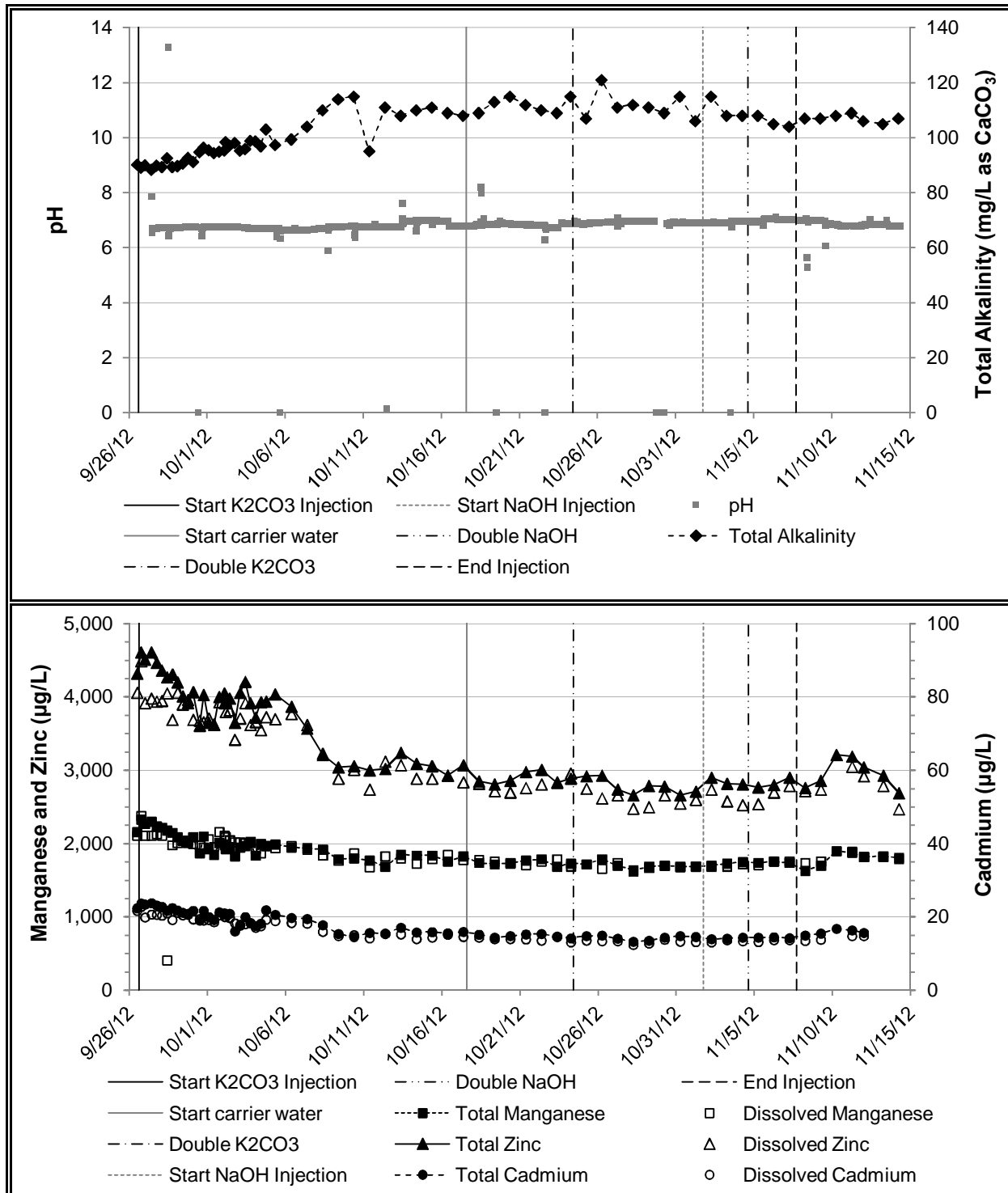


**FIGURE 4-1**  
**2012 INJECTION TEST**  
**517 SHAFT SELECT WATER QUALITY PARAMETERS AND ANALYTES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**

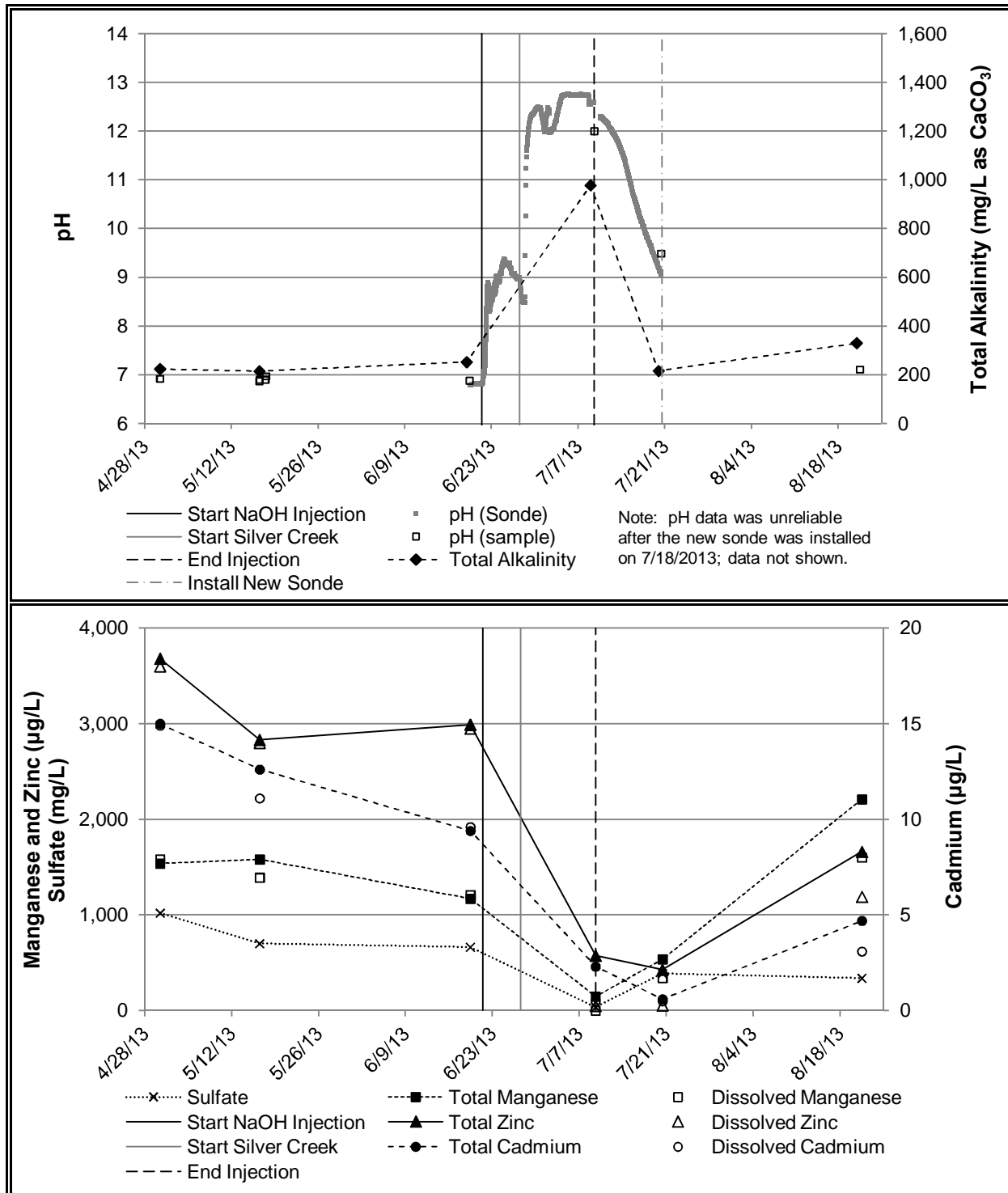




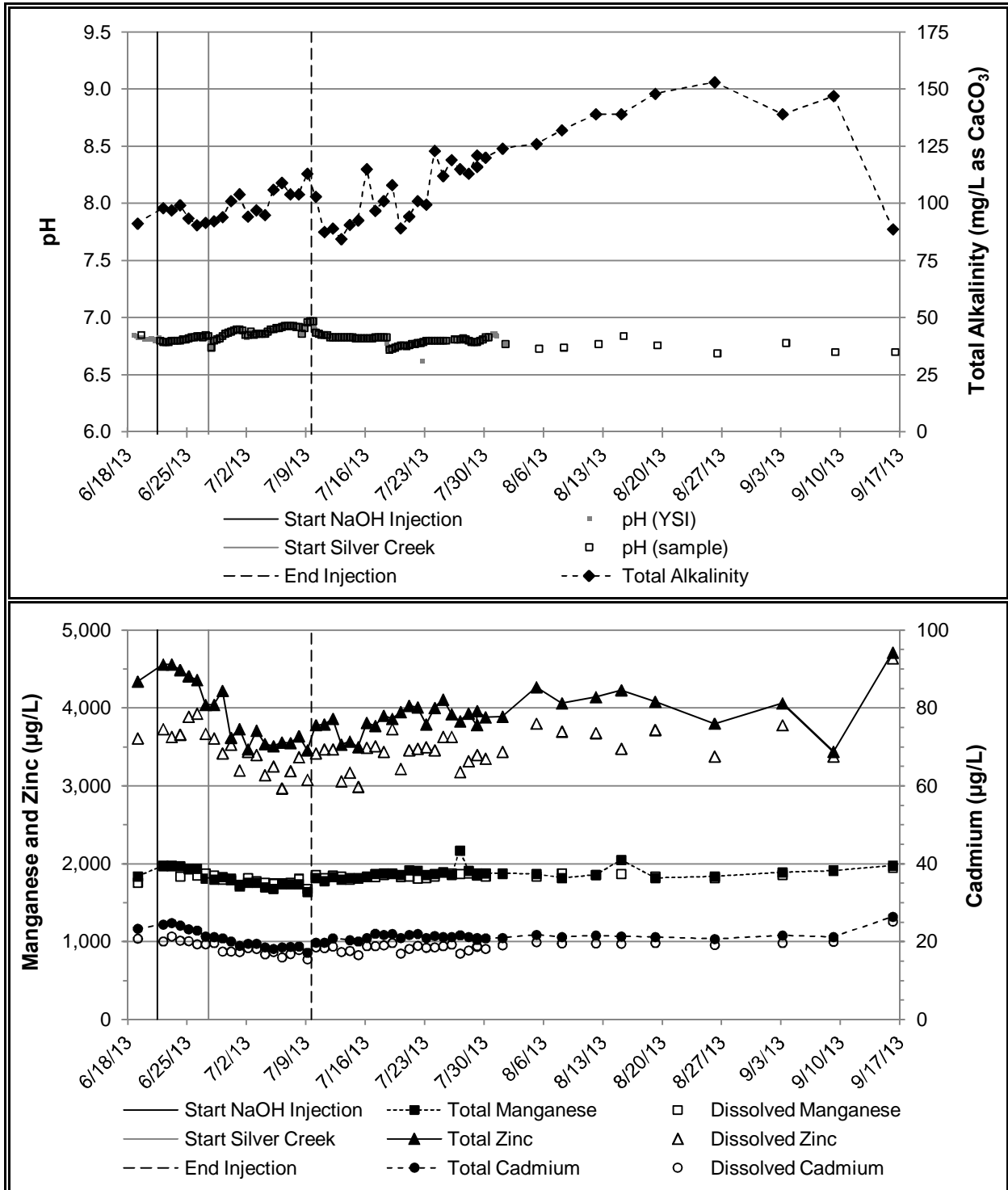
**FIGURE 4-2**  
**2012 INJECTION TEST**  
**DR-3A SELECT WATER QUALITY PARAMETERS AND ANALYTES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



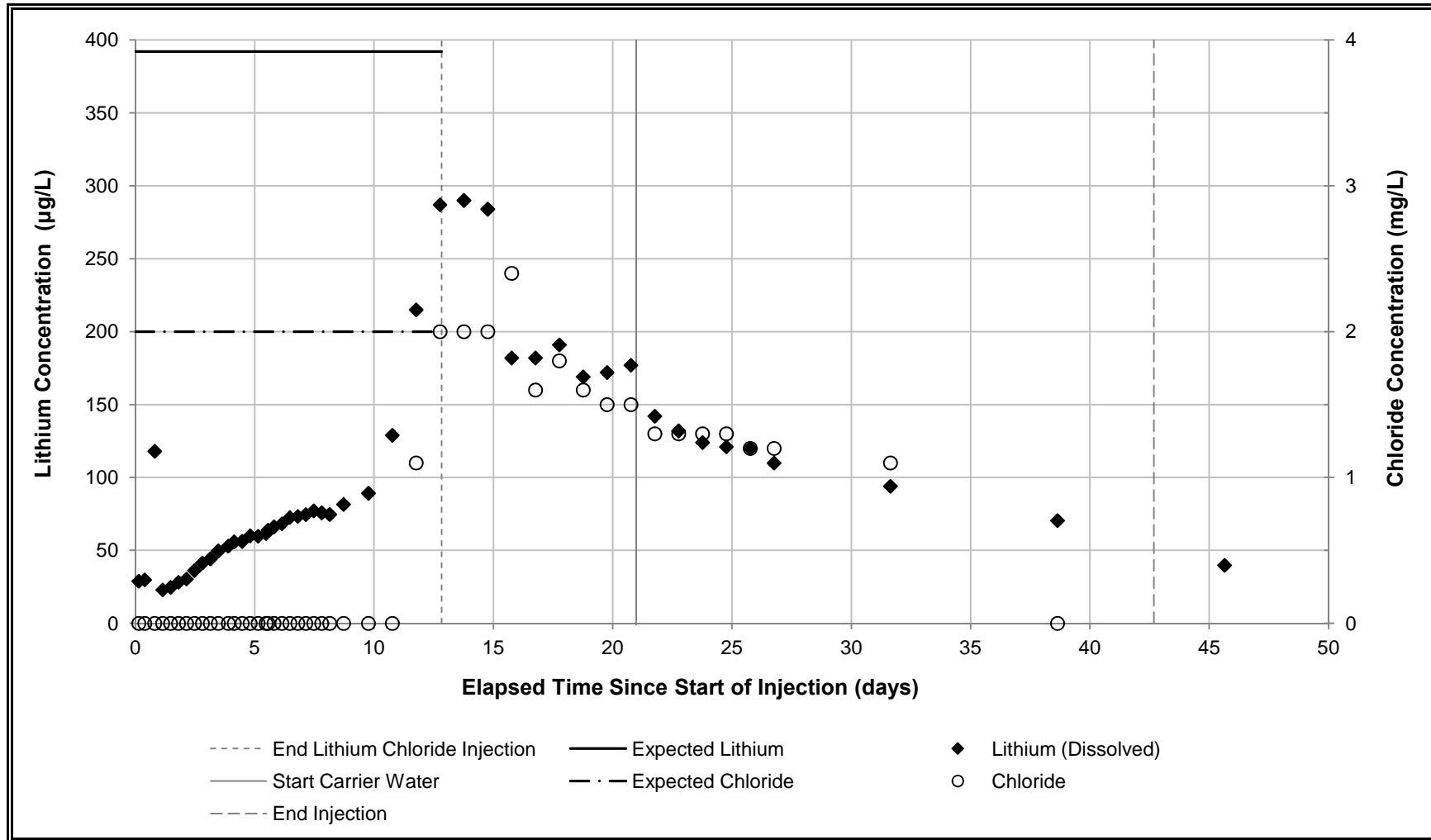
**FIGURE 4-3**  
**2013 INJECTION TEST**  
**517 SHAFT SELECT WATER QUALITY PARAMETERS AND ANALYTES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



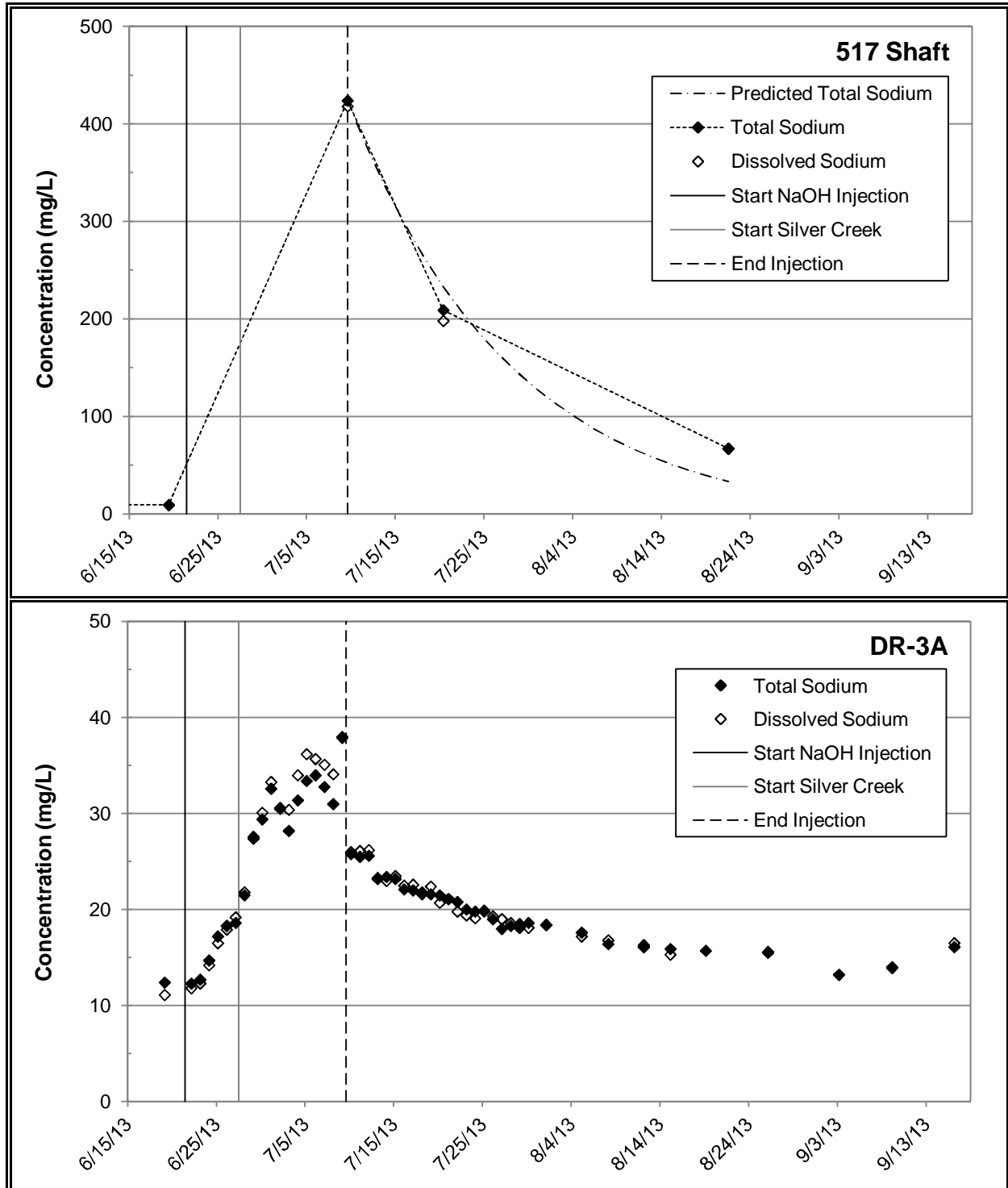
**FIGURE 4-4**  
**2013 INJECTION TEST**  
**DR-3A SELECT WATER QUALITY PARAMETERS AND ANALYTES**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



**FIGURE 4-5**  
**2012 INJECTION TEST**  
**TRACER TEST RESULTS AT DR-3A**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



**FIGURE 4-6**  
**2013 INJECTION TEST**  
**TRACER TEST RESULTS**  
**EVALUATION OF SOURCE WATER CONTROLS**  
**Rico-Argentine Mine Site**  
**Dolores County, Colorado**



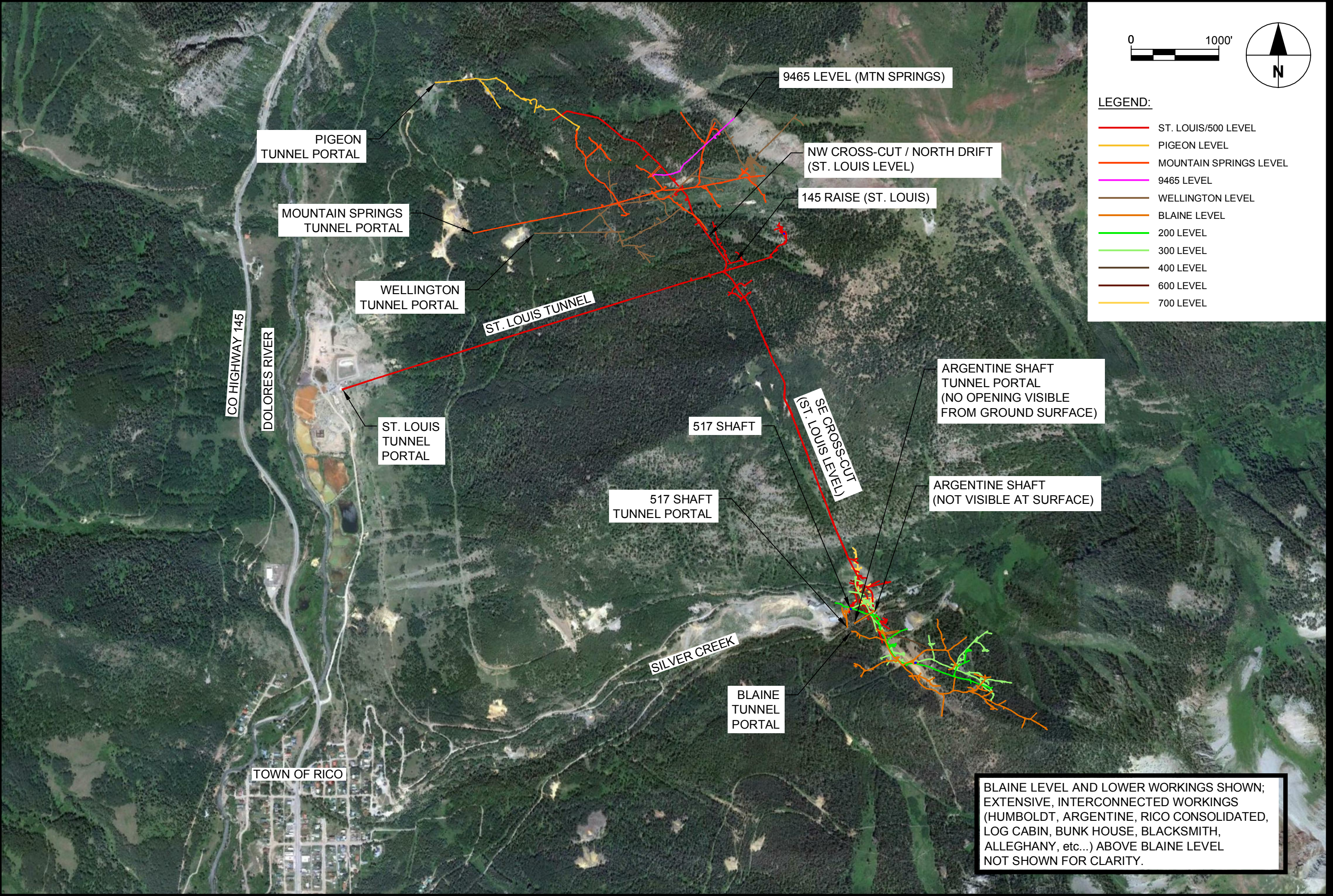
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**ATTACHMENT 1**

AECOM Mine Workings Figures



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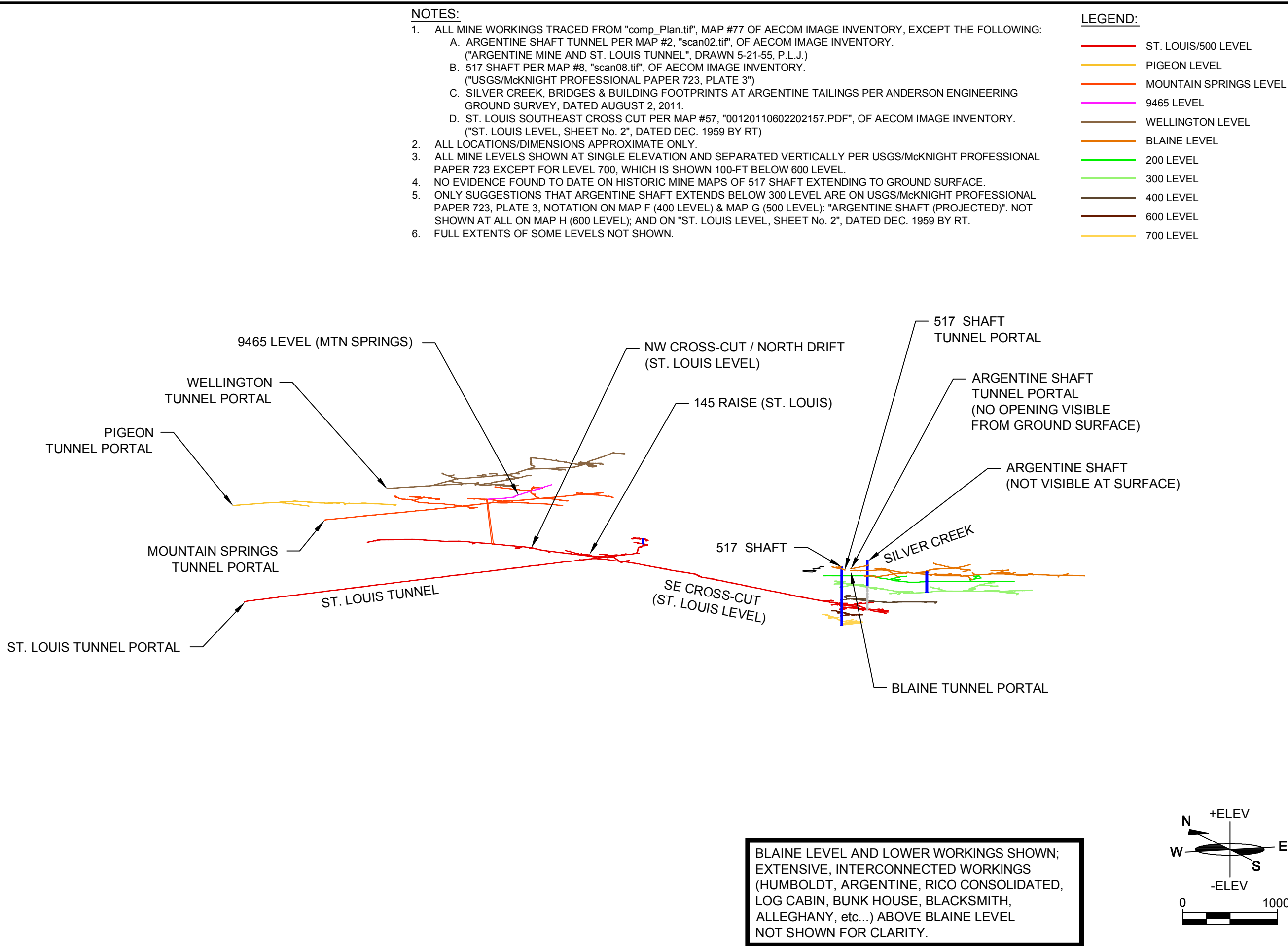


**RICO-ARGENTINE SITE-OU01**

MINE WATER MODEL PLAN OVERVIEW

FIGURE 1





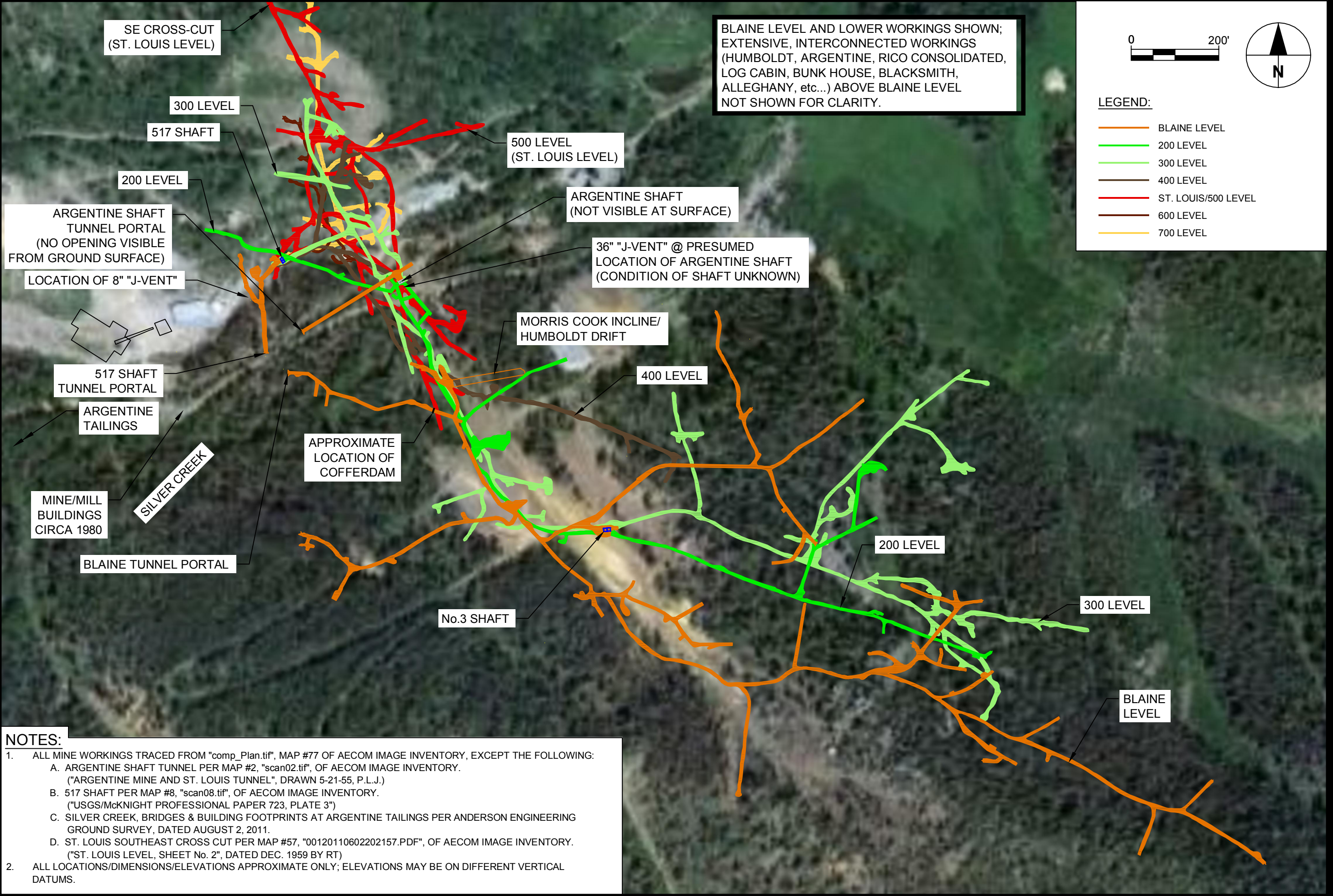
**RICO-ARGENTINE SITE-OU01**

MINE WATER MODEL PERSPECTIVE OVERVIEW

FIGURE 2

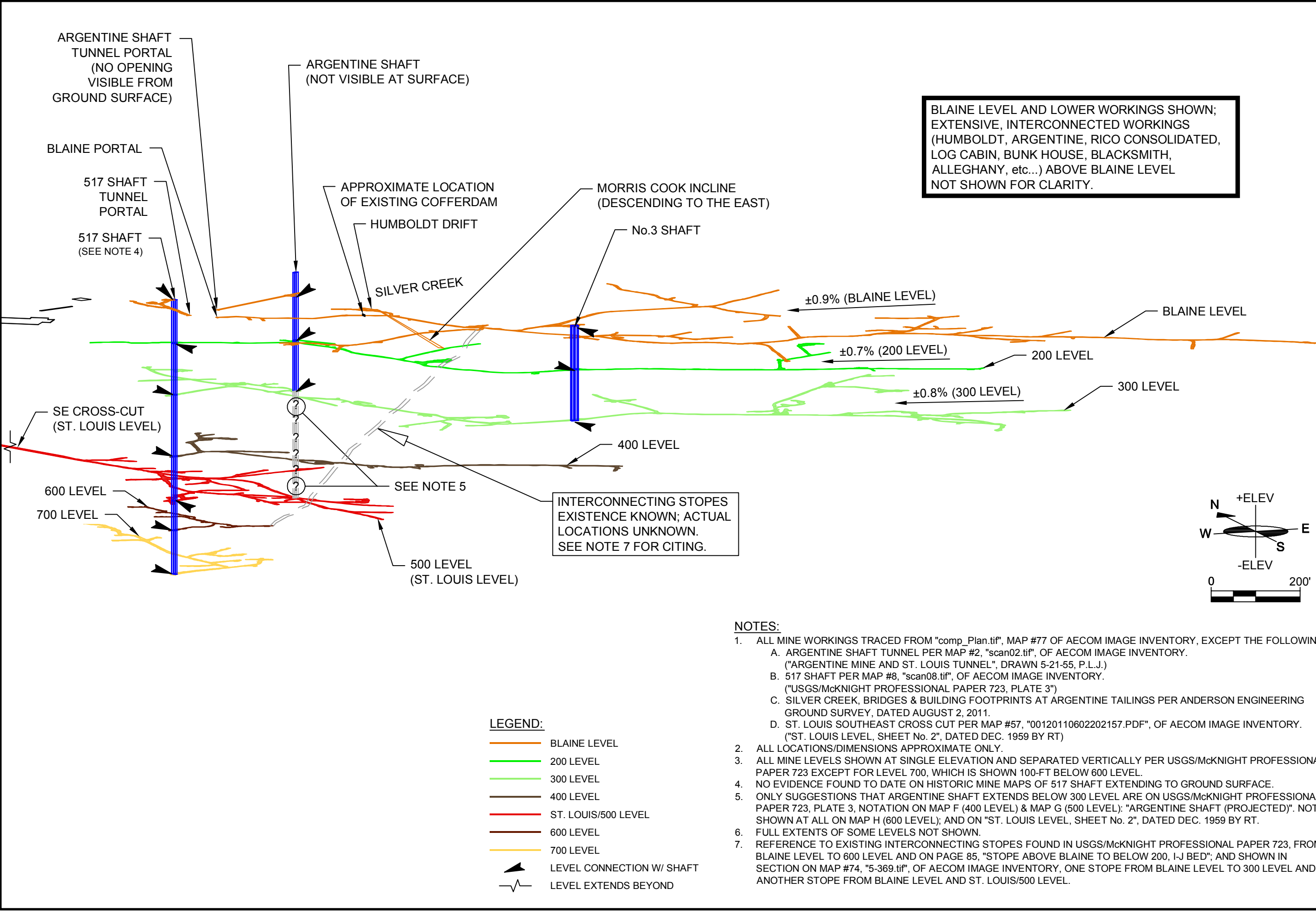


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- NOTES:**
- ALL MINE WORKINGS TRACED FROM "comp\_Plan.tif", MAP #77 OF AECOM IMAGE INVENTORY, EXCEPT THE FOLLOWING:
    - ARGENTINE SHAFT TUNNEL PER MAP #2, "scan02.tif", OF AECOM IMAGE INVENTORY. ("ARGENTINE MINE AND ST. LOUIS TUNNEL", DRAWN 5-21-55, P.L.J.)
    - 517 SHAFT PER MAP #8, "scan08.tif", OF AECOM IMAGE INVENTORY. ("USGS/McKNIGHT PROFESSIONAL PAPER 723, PLATE 3")
    - SILVER CREEK, BRIDGES & BUILDING FOOTPRINTS AT ARGENTINE TAILINGS PER ANDERSON ENGINEERING GROUND SURVEY, DATED AUGUST 2, 2011.
    - ST. LOUIS SOUTHEAST CROSS CUT PER MAP #57, "00120110602202157.PDF", OF AECOM IMAGE INVENTORY. ("ST. LOUIS LEVEL, SHEET No. 2", DATED DEC. 1959 BY RT)
  - ALL LOCATIONS/DIMENSIONS APPROXIMATE ONLY.
  - ALL MINE LEVELS SHOWN AT SINGLE ELEVATION AND SEPARATED VERTICALLY PER USGS/McKNIGHT PROFESSIONAL PAPER 723 EXCEPT FOR LEVEL 700, WHICH IS SHOWN 100-FT BELOW 600 LEVEL.
  - NO EVIDENCE FOUND TO DATE ON HISTORIC MINE MAPS OF 517 SHAFT EXTENDING TO GROUND SURFACE.
  - ONLY SUGGESTIONS THAT ARGENTINE SHAFT EXTENDS BELOW 300 LEVEL ARE ON USGS/McKNIGHT PROFESSIONAL PAPER 723, PLATE 3, NOTATION ON MAP F (400 LEVEL) & MAP G (500 LEVEL): "ARGENTINE SHAFT (PROJECTED)". NOT SHOWN AT ALL ON MAP H (600 LEVEL); AND ON "ST. LOUIS LEVEL, SHEET No. 2", DATED DEC. 1959 BY RT.
  - FULL EXTENTS OF SOME LEVELS NOT SHOWN.
  - REFERENCE TO EXISTING INTERCONNECTING STOPES FOUND IN USGS/McKNIGHT PROFESSIONAL PAPER 723, FROM BLAINE LEVEL TO 600 LEVEL AND ON PAGE 85, "STOPE ABOVE BLAINE TO BELOW 200, I-J BED"; AND SHOWN IN SECTION ON MAP #74, "5-369.tif", OF AECOM IMAGE INVENTORY, ONE STOPE FROM BLAINE LEVEL TO 300 LEVEL AND ANOTHER STOPE FROM BLAINE LEVEL AND ST. LOUIS/500 LEVEL.

---

**ATTACHMENT 2**

Historical Documents

RICO ARGENTINE MINING CO.

AREA CODE 303-967-2281

P.O. BOX 158

RICO, COLORADO 81332

December 12, 1977

Mr. Irwin L. Dickstein  
Director Enforcement Division  
United States Environmental Protection Agency  
1860 Lincoln Street  
Denver, Colorado 80203

Ref: 8E-PC

Dear Mr. Dickstein;

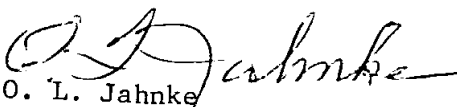
We have taken measures to eliminate the Blaine Tunnel discharge (NPDES permit CO-0029793-001). The discharge was diverted underground to be discharged with the St. Louis water which discharge is processed by our series - decantation ponds. Samples of the discharge (002) have been taken but the results from Commercial Testing and Engineering Company have not been received as yet to determine our net results.

Until recently we have not been plagued as to our discharge. Mining out of the Blaine Tunnel has not been in operation for seven years. The only explanation I can give is our lack of moisture, which in turn has eliminated the dilution factor of our mine discharge.

As of November 21, 1977 the Blain Discharge is none and will remain so until the mine is again reactivated; however, we do wish to hold our discharge permit 001.

I trust this will answer your immediate questions.

Very truly yours,

  
O. L. Jahnke  
General Manager

OLJ:mj  
cc: Mr. Frank Rozich  
Mr. Gregory Hobbs  
Mr. Mike Howell  
Mr. Norman Palermo

**RICO ARGENTINE MINING CO.**

AREA CODE 303-967-2281

P.O. BOX 158

RICO, COLORADO 81332

August 25, 1980

Mr. Jack R. Whyte  
Health, Safety & Envir.  
Anaconda Company  
555 Seventeenth St.  
Denver, Colorado 80217

Dear Mr. Whyte;

The water samples were taken and sent to Commercial Testing, as per instructions. They were instructed to call you for further information.

Samples--Water--Mine Run

Samples were taken on August 18, 1980, from the following discharge points;

Sample #1-----Swan Portal

Sample #2-----Santa Cruz-Dcline Collar

Sample #3-----Total Discharge-St. Louis Portal

Sample #4-----Blaine Tunnel-at the collar of the Blaine Shaft

Sample #5-----St. Louis Tunnel Discharge from the SE Drift

Sample #6-----St. Louis Tunnel Discharge from the North Drift

Sample #7-----St. Louis Tunnel Discharge from the 145 Raise Area

$\frac{2}{3}$

$\frac{3}{12}$

$\frac{1}{12}$

**RICO ARGENTINE MINING CO.**

AREA CODE 303-967-2281

P.O. BOX 158

RICO, COLORADO 81332

Mr. Jack R. Whyte  
August 25, 1980  
Page -2-

If you have any questions, I will be available at any time to answer.

Very truly yours,

OLJ/mj

  
O. L. JAHNKE  
General Manager



J. Whyte ✓

# COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 228 NORTH LA SALLE STREET, CHICAGO, ILLINOIS 60601 AREA CODE 312 726-8434



Reply to  
Instrumental Analysis Division  
490 Orchard Street  
Golden, CO 80401

Phone: 303-278-9521

Sept. 29, 1980

Mr. R. L. Dent  
Anaconda Copper Co.  
555 Seventeenth St.  
Denver, CO 80217

OCT 3 1980

Re: IAD #97-E986-452-09

## ANALYTICAL REPORT

Nine samples were received for analyses on August 25, 1980. These samples were given our identification IAD #97-E986-452-09.

The samples were analyzed for total Zinc, Iron, Cadmium, and Lead by flame atomic absorption spectrophotometry following a rigorous digestion in nitric and hydrochloric acids. Mercury was analyzed directly by cold vapor flameless atomic absorption.

The samples were also analyzed for pH and Fluoride by specific ion electrode and sulfate by turbidimetric methods following the procedures of EPA Methods for Chemical Analysis of Water and Wastes, 1979.

The results of these determinations are presented in the following tables and are reported in milligrams per litre (mg/l) except pH.

Table No. I  
concentration in mg/l

<u>Parameter</u>	<u>#1</u>	<u>#2</u>	<u>#3</u>	<u>#4</u>	<u>#5</u>
pH	*1.9	*3.1	*1.8	*1.8	*1.7
Fluoride	0.06	0.30	4.3	1.7	2.7
Sulfate	253	393	562	769	544
Zinc, total	1.96	1.58	5.2	1.78	2.62
Iron, total	5.4	0.3	16.2	13.2	3.7
Cadmium, total	<0.001	0.005	0.022	0.007	0.009
Lead, total	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury	0.00005	0.00005	0.00005	0.00005	0.00005



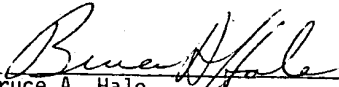
Sept. 29, 1980

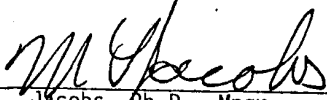
Table No. II  
concentration in mg/l

Parameter	#6	#7	#8	#9
pH	*2.0	*1.8	7.6	7.0
Fluoride	18	1.7	5.6	5.8
Sulfate	1070	505	670	620
Zinc, total	27	0.50	1.28	5.00
Iron, total	102	5.6	0.13	12.8
Cadmium, total	0.107	<0.001	<0.007	0.029
Lead, total	0.13	<0.05	<0.05	<0.05
Mercury	0.00005	0.00007	0.00005	0.00005
Cyanide	----	----	<0.01	----

\*pH value may be low due to the possibility that the sample may have been preserved w/acid.

If there are any questions concerning these results, please call.

  
Bruce A. Hale  
Section Supervisor

  
M. L. Jacobs, Ph.D., Mngr.  
Instrumental Analysis Div.

BAH/jw

COMMERCIAL TESTING &amp; ENGINEERING CO.

Original Copy Watermarked  
For Your Protection

F 465



Rico



Date: May 21, 1982


Subject: Water Quantity and Quality, St. Louis Tunnel: Rico

From/Location: Jack Whyte

To/Location: John Wilson

I have attached a letter from O. Jahnke dated August 25, 1980 that provides the results of water quality analyses on samples from our underground flows. Specific to our recent conversation, I have summarized results of interest below:

<u>Parameter</u>	<u>Total Discharge St. Louis Portal</u>	<u>SE Drift St. Louis</u>	<u>North Drift St. Louis</u>	<u>145 Rise St. Louis</u>
Estimated portion of flow	Total	2/3	3/12	1/12
Zinc (total) (Mg/l)	5.2	2.62	27	0.50

  
J. Whyte  
Environmental Services Manager

JW/cc

4-2  
W

Date: August 27, 1985

Subject: Water Analyses from Contributory Sources

From/Location: D. Cameron -- Rico

To/Location: G. Secor -- DAT

Shutting off part of the water flow to the St. Louis Tunnel is part of the long-term but low-cost options for the Rico problem. Enclosed are results of some water samples taken at various points in the drainage:

	Zn	Cd	ppm	
SL-1	27	0.010		Nw crosscut, St. Louis Tunnel
SL-2	3.5	0.016		SE crosscut, " " "
SL-3	n.d.	n.d.		" " ", drill hole in back 15 gpm
SL-4	1.0	0.003		" " ", Iron Rod raise, SW side
B-1	27	0.11		Blaine Level seep to portal
B-2	0.96	0.006		" " " , diversion to lower workings.

The highest flow of dirty water is out of the NW crosscut, and we can do nothing about it that I can recommend. We will try to plug the drill hole. Note that the Blaine water and the Southeast crosscut water are not clean as far as Zn and Cd. I believe we can eliminate much of this flow.

I have collected samples from other St. Louis Tunnel holes which I intend to plug pending receipt of hardware. These could serve as pure water supplies (e.g., SL-3) in any plant modification. I will also sample the mine water again as soon as assessment work stops. Enclosed are the new drill hole sample numbers submitted to Rocky Mountain:

SL-5	SE crosscut, warm water ddh. 15 gpm
BB-1H	" " " , BB-1 drill station, angle hole
BB-1	" " " , vertical hole
BB-2H	" " " , BB-2 drill station, angle hole
BB-2	" " " , vertical hole

---

**ATTACHMENT 3**

Blaine Tunnel 2012-2013 Documentation

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**ATTACHMENT 3-1**

Blaine Tunnel Flume Design



## VIRTUAL POLYMER COMPOUNDS, LLC

10478 Ridge Road • Medina, New York 14103  
Phone: 585-735-9668 • Toll Free: 888-290-9522  
Fax: 585-735-9965 • [www.virtualpolymercompounds.com](http://www.virtualpolymercompounds.com)

Administrative Office: One John James Audubon Pkwy • Amherst, NY 14228

# Extra Large Trapezoidal Flume

Head Feet	CFS	GPM
0.03	0.000	0.07
0.05	0.001	0.26
0.10	0.004	1.16
0.15	0.010	4.67
0.20	0.022	9.98

0.25	0.040	17.97
0.30	0.065	29.06
0.35	0.097	43.63
0.40	0.138	62.05
0.45	0.189	84.64

Head Feet	CFS	GPM
0.50	0.249	111.74
0.55	0.320	143.66
0.60	0.403	180.70
0.65	0.497	223.16
0.70	0.605	271.30

0.75	0.725	325.42
0.80	0.860	385.78
0.85	1.009	452.64
0.90	1.173	526.25
0.95	1.352	606.87





# VIRTUAL POLYMER COMPOUNDS, LLC

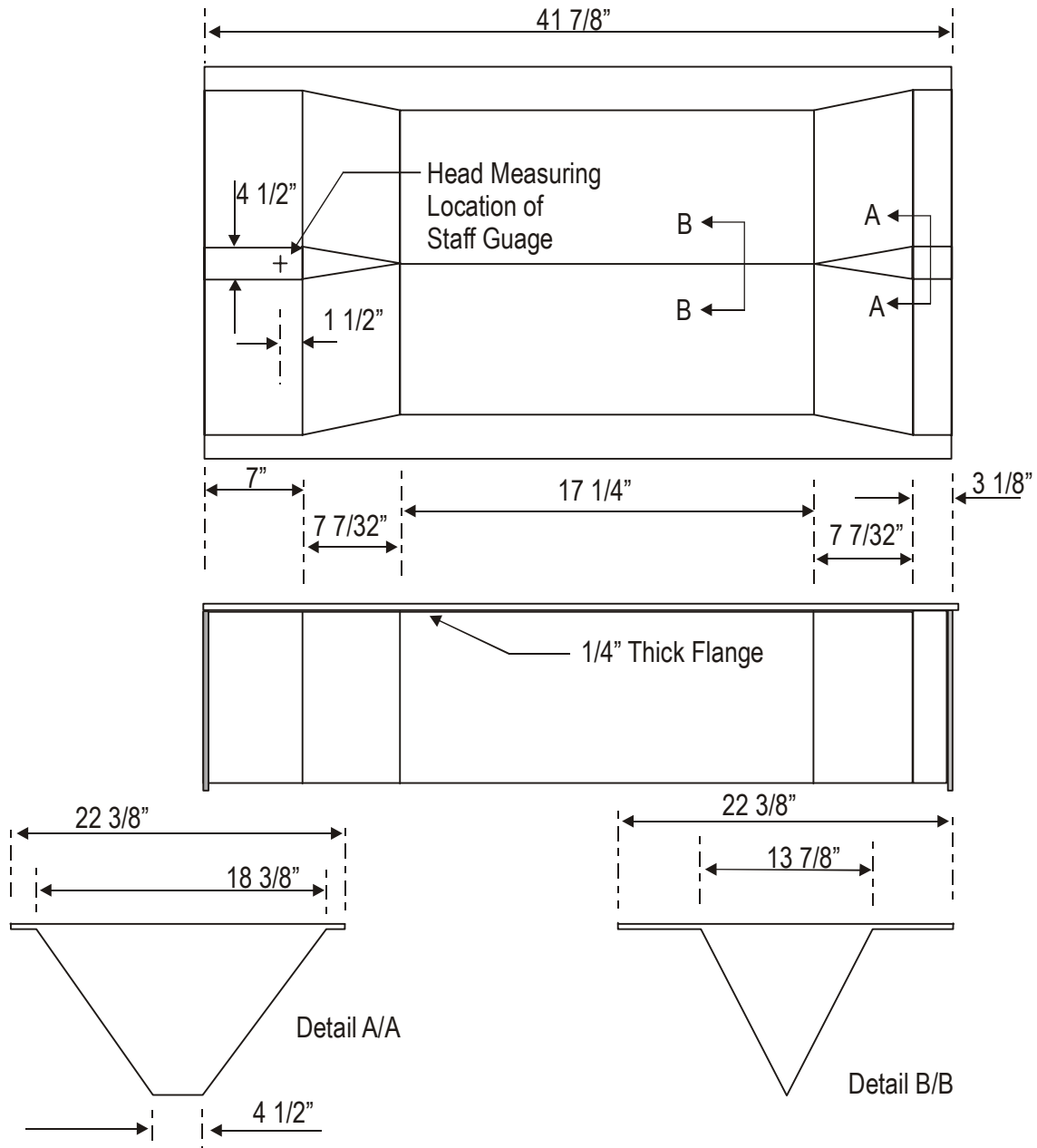
10478 Ridge Road • Medina, New York 14103

Phone: 585-735-9668 • Toll Free: 888-290-9522

Fax: 585-735-9965 • [www.virtualpolymercompounds.com](http://www.virtualpolymercompounds.com)

Administrative Office: One John James Audubon Pkwy • Amherst, NY 14228

## Extra Large Trapezoidal Flume



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**ATTACHMENT 3-2**

Hach Sigma 950 Ultrasonic Depth Sensor Specifications

# Sigma 950 Series Permanent/Portable Open Channel Flow Meters

*Sigma 950 Series Permanent/Portable Open Channel Flow Meters provide portable and/or permanent single-channel monitoring plus water quality testing, process control interface, and digital display. Both models offer maximum flexibility for multiple applications—including surcharge or reversed flow conditions, weirs and flumes, and small-to-large channels. Up to three different level sensor technologies and velocity in one meter.*



## Features and Benefits

### Versatility and Customization

The Sigma 950 series are the meters of choice by flow professionals, consultants, and municipalities. Choose from any of the following technologies to fit your application.

- *Use the Submerged Area/Velocity flow meter to measure flow in collections systems for periods up to 40 days using our 6 amp-hr gel electrolyte battery.*
- *Use any of our level technologies when primary devices (Weirs and Flumes) are available to measure level and calculate flow.*
- *The bubbler level technology is ideal for applications with high winds, high temperature or when foam is present.*
- *The combination of bubbler level technology and doppler velocity is the favorite of storm water professionals.*
- *The ultrasonic level technology is ideal to monitor industrial discharges for your Pre-treatment program in combination of any of our Automatic Wastewater samplers.*

### Sampler Pacing and Equipment Control

Control samplers, pumps, or other equipment for monitored flow based on selected parameter(s) of high/low set points and built-in relay outputs. Sampler pacing provides the ability to document overflow problems.

### Easy to Use Interface

The large LCD graphics quickly displays information on-site (available in 10 languages) without the inconvenience of paper charts. The built-in keypad makes using laptops in the field optional. A single keystroke can provide an instantaneous data summary and review of all program settings.

### Communications and Data Storage Options

Industry standard SCADA MODBUS ASCII protocol is included in all Sigma 950 flow meters. 4-20 mA outputs are available for flexible integration with a SCADA system. Remote communications is available via modem or RS-232 connection. Store 18,000 data points in memory (expandable to 116,000 data points).

### Superior Submersible Area Velocity Sensor for Open Channel Applications

The Sigma 950 AV Optiflo flow meter provides Doppler velocity monitoring that uses advanced ultrasonic, one-MHz Doppler technology for flow measurements. This technology avoids signal dropouts and ensures high levels of accuracy in low-flow, full-pipe, or reversed-flow conditions. Installation is fast and single point atmospheric calibration is easy.

### Applications

Sigma 950 Permanent/Portable Open Channel Flow Meter

- *Long term or permanent flow studies*
- *Sanitary sewer evaluation studies*
- *CSO studies and monitoring*
- *NPDES stormwater compliance*
- *Industrial compliance monitoring*

Sigma 950 AV Optiflo Permanent/Portable Open Channel Flow Meter

- *Applications involving frequent moving of meter to different site conditions*

DW = drinking water WW = wastewater municipal PW = pure water / power  
IW = industrial water E = environmental C = collections FB = food and beverage



Be Right™

WW

IW

C

## Specifications\*

### Flow Meter Specifications

#### Units of Measurement

Flow: gps, gpm, gph, lps, lpm, lph, mgd, afd, cfs, cfm, cfh, cfd, m<sup>3</sup>s, m<sup>3</sup>m, m<sup>3</sup>h, m<sup>3</sup>d

Totalized Flow: L, m<sup>3</sup>, ft.<sup>3</sup>, gal., acre-ft.

#### Primary Devices

Flumes: Parshall, Palmer Bowlus, Leopold-Lagco, H, HL, HS, trapezoidal  
Weirs: V-notch (22.5 to 120°)  
Contracted/non-contracted rectangular, Thelmar, Compound Cipolletti  
Manning Equation: Round, U rectangular, and trapezoidal channels  
Flow Nozzles: California Pipe  
Head vs. Flow: Custom programmable curve (up to 99 points)

#### Operating Temperature

-10 to 65.5°C (14 to 150°F)

#### Storage Temperature

-40 to 80°C (-40 to 176°F)

#### Humidity

0 to 100%, condensing

#### Time-Based Accuracy

±6 seconds (± 0.007%) per day

#### Air Intake

Atmospheric pressure reference is desiccant protected

#### Totalizers

8-digit resettable and 8-digit non-resettable LCD software totalizer  
Optional 6-digit non-resettable mechanical totalizer

### Sensor Specifications

#### 950 BUBBLER SENSOR

##### Range

0.003 to 3.6 m (0.01 to 11.75 ft.)

##### Accuracy

±0.003 m (±0.011 ft.)  
(linearity and hysteresis at 22°C (72°F))  
from 0.01 to 11.75 feet

##### Ambient Operating Temperature

-18 to 63°C (0 to 145°F)

##### Compensated Temperature

0 to 59°C (32 to 138°F)

##### Temperature Error

±0.0003 ft./°F (maximum error within compensated temperature range per degree of change)

##### Air Intakes

Bubble source and reference port desiccant protected.  
Fittings provided for remote intakes.

#### Graphics Display

Back lit LCD  
Auto-off when not in use (under battery operation)  
SCII Mode: 8 line x 40 character  
Graphics Mode: 60 x 240 dot  
Dimensions: 3.8 x 12.7 cm (1.5 x 5 in.)  
Displays: level vs. time, flow vs. time  
Optional Displays: rainfall, pH, ORP, temperature, DO, conductivity vs. time, sampler events, and alarm events

#### Keypad

21 position sealed membrane switch with blinking green LED to indicate power on  
Four "soft keys", functions defined by display

#### Data Logging

"Smart" Dynamic memory allocation automatically partitions memory to provide the maximum logging time. No manual memory partitioning required.

Memory Mode: Either slate or wrap-around may be selected

Data Points: Approximately 20,000 standard. Expandable up to 116,000 data points.

Daily Statistics: Available for up to 32 days

Recording Intervals: 1, 2, 3, 5, 6, 10, 12, 15, 20, 30, or 60-minute intervals

#### Program Memory

Non-volatile programmable flash, can be updated via RS-232 port

#### Sampler Output

12 to 17 Vdc pulse, 100 mA maximum at 500 ms duration

#### Communications

RS-232: Up to 19,200 baud  
SCADA MODBUS communication protocol via RS-232 or optional modem  
Modem (optional): 14,400 bps; V.32 bis, V.42, MNP2-4 error correction. V.42 bis MNP5 data compression. MNP 10-EC Cellular Protocol Pager

#### Enclosure Material

ABS, UV resistant

#### Enclosure Rating

NEMA 4X,6

#### Power Options

12 Vdc supplied from 6 amp-hr. gel electrolyte rechargeable battery  
4 amp-hr. Ni-Cad rechargeable battery  
Lantern battery pack with two 6-Volt lantern batteries  
115 Vac, 230 Vac, or 100 Vac power converter with battery charger

#### Dimensions

34.3 H x 25.4 W x 24.1 D cm  
(13.5 x 10.0 x 9.5 in.)

#### Weight

5 kg (11 lbs.) not including power source

#### Filter

10 micron on bubble source intake

#### Line Purge

Bubble line is high pressure purged at programmed intervals, or in manual mode on demand

#### Line Size

0.32 cm (1/8 in.) ID standard

#### Line Lengths

160 m (500 ft.) maximum

#### 950 DOWNLOOKING ULTRASONIC DEPTH SENSOR

##### 50 kHz Ultrasonic Sensor

##### Range

38.1 cm to 9.1 m (15 in. to 30 ft.) sensor to liquid

##### Accuracy

1 to 10 ft. ±0.01 ft. (±0.003 m)  
(at 22°C (72°F), still air, 40 to 70% relative humidity)

#### Span

0 to 8.84 m, (0 to 29 ft.)

#### Ambient Operating Temperature

-18 to 60°C (0 to 140°F)

#### Temperature Error

±0.000047 ft./°F (maximum error within compensated temperature range per degree of change)

#### Resolution

0.0011 ft.

#### Material

PVC housing  
Buna-N acoustic window

#### Cable

4-conductor with integral stainless steel support cable  
Standard Length: 7.6 m (25 ft.)

*Continued on next page.*



## Specifications *continued*

### Crystal Specification

11.5° included beam angle

### Dimensions

9.5 H x 7 D cm (3.75 x 2.75 in.)

### Weight

0.7 kg (1.5 lbs.)

### 75 kHz Ultrasonic Sensor

#### Range

23 cm to 3.3 m (9 in. to 10.8 ft.)  
sensor to liquid

#### Accuracy

1 to 10 ft.  $\pm 0.01$  ft. ( $\pm 0.003$  m)  
(at 22°C (72°F), still air, 40 to 70%  
relative humidity)

#### Span

0 to 4.57 m (0 to 15 ft.)

#### Ambient Operating Temperature

-18 to 60°C (0 to 140°F)

#### Temperature Error

$\pm 0.00047$  ft./°F (maximum error within  
compensated temperature range per  
degree of change)

#### Resolution

0.0011 ft.

#### Material

PVC housing  
Buna-N acoustic window

#### Cable

4-conductor with integral stainless steel  
support cable  
Length: 7.6 m (25 ft.) standard

### Crystal Specification

5° beam angle with horn

### Dimensions

12.7 H x 5.7 D cm (5.0 x 2.25 in.)

### Weight

0.7 kg (1.5 lbs.)

### 75 KHZ IN-PIPE ZERO DEADBAND ULTRASONIC DEPTH SENSOR

#### Range

From sensor to liquid,  
0 to 2.4 m (0 to 8 ft.)

#### Accuracy

0.038 to 2.4 m  $\pm 0.003$  m  
(0.125 to 8 ft.  $\pm 0.01$  ft.)  
at 22°C (72°F), still air, 40 to 70%  
relative humidity

### Span

0.038 to 4.57 m (0.125 to 15 ft.)

### Ambient Operating Temperature

-18 to 60°C (0 to 140°F)

### Temperature Error

$\pm 0.00005$  m/°C ( $\pm 0.0001$  ft./°F)  
maximum error within compensated  
temperature range per degree of change

### Resolution

0.019 cm (0.0075 in.)

### Material

Stat-Kon® A-E ABS Plastic

### Cable

4-conductor  
Standard Length: 7.6 m (25 ft.)  
Custom Length: Up to 305 m (1000 ft.)  
using RS485 two wire remote sensor  
option

### Crystal Specification

7° beam angle

### Dimensions

4.44 D x 31.5 L cm (1.75 x 12.4 in.)

### Connection

Bare lead connection via 3658 junction  
box or quick connect

### 950 SUBMERGED DEPTH ONLY SENSOR

#### Range

2.5 psi: 0.01 to 1.75 m (0.04 to 5.75 ft.)

#### Accuracy

$\pm 0.1\%$  full scale (non-linearity and  
hysteresis)

#### Transducer

Type: Differential piezo resistive with  
balanced bridge  
Orientation: Inverted

#### Maximum Allowable Level

6x over pressure

#### Ambient Operating Temperature

0 to 71°C (32 to 160°F)

#### Compensated Temperature

0 to 36°C (32 to 96°F)

#### Temperature Error:

2.5 psi: 0.04 to 5.75 ft.  $\pm 0.006$  ft./F°  
(Max error within compensated temp  
range per degree of change)

#### Air Intake

Atmospheric pressure reference is  
desiccant protected

#### Material

316 stainless steel body with titanium  
diaphragm

### Cable

4-conductor polyurethane sensor  
cable with air vent  
Length: 7.6 m (25 ft.) standard;  
76 m (250 ft.) maximum

### Dimensions

Transducer Only: 2.54 x 17.2 cm  
(1 x 6.75 in.)  
Probe Frontal Area: 0.875 in<sup>2</sup>

### Weight

0.7 kg (1.5 lbs.)

### SUBMERGED AREA/VELOCITY SENSOR

#### Velocity Measurement

#### Method

Doppler ultrasound Twin 1 MHz  
piezoelectric crystals

#### Accuracy<sup>1</sup>

$\pm 2\%$  of reading

#### Recommended Range

-1.52 to 6.10 m/s (-5 to 20 ft/s)

#### Typical Minimum Depth

2 cm (0.8 in.)

#### Zero Stability

< 0.015 m/s (< 0.05 ft/s)

#### Depth Measurement

#### Method

Pressure transducer with stainless steel  
diaphragm

#### Accuracy<sup>2</sup>

$\pm 0.16\%$  full scale  $\pm 1.5\%$  of reading at  
constant temp ( $\pm 2.5^\circ\text{C}$ )  
 $\pm 0.20\%$  full scale  $\pm 1.75\%$  of reading  
from 0 to 30°C (32 to 86°F)  
 $\pm 0.25\%$  full scale  $\pm 2.1\%$  of reading from  
0 to 70°C (32 to 158°F)

#### Depth Range

Standard: 0 to 3 m (0 to 10 ft.)  
Extended: 0 to 9 m (0 to 30 ft.)

#### Maximum Allowable Depth

Standard: 10.5 m (34.5 ft.)  
Extended: 31.5 m (103.5 ft.)

#### Velocity-Induced Depth Error

Compensated based on pipe geometry  
and flow velocity

#### Air Intake

Atmospheric pressure reference is  
desiccant protected

<sup>1</sup>When the sensor is out of the water, the system may report  
velocity readings of up to 0.76 m/s due to Radio Frequency  
Interferences at frequencies of 140 MHz to 170 MHz and 300  
MHz with field strengths greater than 3 V/m.

<sup>2</sup>For temperatures above 40°C (104°F) add  $\pm 0.3$  cm/°C  
(0.03 in./°F)

*Continued on next page.*

## Specifications *continued*

### General

#### **Material**

Noryl® plastic outer shell with epoxy potting within

#### **Power Consumption**

≤ 1.2 W @ 12 Vdc

#### **Cable**

**Material:** Urethane cable with air vent  
**Standard Length:** 9, 15, 23 and 30.5m (30, 50, 75 and 100 ft.)

**Custom Length:** 30.75 to 76 m (101 to 250 ft.) maximum

**Diameter:** 0.91 cm (0.36 in.)

#### **Dimensions**

2 H x 3.8 W x 13.5 L cm  
(0.8 x 1.5 x 5.31 in.)

#### **Operating Temperature**

0 to 70°C (32 to 158°F)

#### **Depth Compensated Temperature**

0 to 70°C (32 to 158°F)

### BUBBLER AREA/VELOCITY SENSOR

#### **Depth Measurement**

#### **Method**

Doppler principle/pressure transducer

#### **Range**

0.003 to 3.6 m (0.01 to 11.75 ft.)

#### **Accuracy**

0.01 to 11.75 ft. ±0.011 ft. (0.033 m)  
(linearity and hysteresis at 22°C (72°F))

#### **Ambient Operating Temperature**

-18 to 63°C (0 to 145°F)

#### **Compensated Temperature**

0 to 59°C (32 to 136°F)

#### **Temperature Error**

±0.0003 ft./°F (maximum error within compensated temperature range per degree of change)

#### **Air Intakes**

Bubble source and reference port desiccant protected.  
Fittings provided for remote intakes.

#### **Filters**

10 micron on bubble source intake

#### **Line Purge**

Bubble line is high pressure purged at programmed intervals, or in manual mode on demand

#### **Velocity Measurement**

#### **Method**

Doppler ultrasonic

#### **Transducer Type**

Twin 1 MHz piezoelectric crystals

#### **Range**

-1.52 to 6.10 m/s (-5 to 20 fps)

#### **Zero Stability**

< 0.015 m/s (0.05 fps)

#### **Accuracy**

±2% of reading

#### **Depth for Velocity**

2 cm (0.8 in.) minimum, typical

#### **Operating Temperature**

-18 to 60°C (0 to 140°F)

#### **Dimensions**

1.12 x 3.81 x 6.86 cm  
(0.44 x 1.5 x 2.7 in.)

### LOW PROFILE VELOCITY ONLY SENSOR

#### **Method**

Doppler principle

#### **Accuracy**

±2% of reading

#### **Range**

-1.52 to 6.1 ms (-5 to +20 ft/s)

#### **Zero Stability**

±1.52 cm/s (±0.05 ft/s)

#### **Resolution**

0.3 cm/s (0.01 ft/s)

#### **Response Time**

4.8 seconds

#### **Profile Time**

4.8 seconds

#### **Nose Angle**

20° from horizontal

#### **Cable**

**Length:** 7.6 m (25 ft.) standard; custom cable lengths to 76 m (250 ft.)  
**Diameter:** 0.57 cm (0.225 in.)

#### **Materials**

**Sensor:** Polymer

**Cable:** Urethane Jacket

**Mounting Hardware:** Stainless steel

#### **Dimensions**

6.86L x 3.81W x 1.12H cm  
(2.7 x 1.5 x 0.44 in.)

## Factory Installed Options

### pH-TEMPERATURE OR ORP METER

#### **Control/Logging**

Log pH-temperature or ORP independent of flow or in conjunction with flow; also controls sample collection in response to value exceeding low/high set points

#### **pH/Temperature Sensor**

Temperature compensated; impact resistant ABS plastic body; combination electrode with porous Teflon® junction

#### **Measurement Range**

2 to 12 pH within specifications;  
0 to 14 pH maximum range

#### **Operating Temperature**

-18 to 80°C (0 to 176°F)

#### **Recording Intervals**

1, 2, 3, 5, 6, 10, 12, 15, 30, and 60 minutes

#### **Probe Pre-Amplifier/Junction Box**

NEMA 4X with labeled terminal strip

#### **Dimensions**

1.9 x 15.2 cm (0.75 x 6 in.) with  
1.9-cm (0.75-in.) MPT cable end

### INTEGRAL DISSOLVED OXYGEN METER

#### **Control/Logging**

Field selectable to log dissolved oxygen independent of flow or in conjunction with flow; also controls sample collection in response to value exceeding low/high set points

#### **Measurement Method**

Polargraphic

#### **Sensor**

Temperature compensated; impact resistant polypropylene body

*Continued on next page.*

## Specifications *continued*

### **Measurement Range**

0 to 20 mg/L dissolved oxygen

### **Resolution**

0.01 mg/L

### **Accuracy**

±0.2 mg/L

### **Operating Temperature**

0 to 50°C (32 to 122°F)

### **Dimensions**

1.65 x 12.7 cm (0.65 x 5 in.) with  
1.9-cm (0.75-in.) MPT cable end

### **INTEGRAL**

### **CONDUCTIVITY/TEMPERATURE METER**

#### **Control/Logging**

Field selectable to log conductivity independent of flow or in conjunction with flow, also controls sample collection in response to value exceeding low/high set points

#### **Sensor**

Temperature compensated;  
impact resistant polypropylene body

### **Measurement Range**

0 to 100 mS/cm

### **Resolution**

0.01 mS/cm or 0.01 µS/cm  
(user selectable)

### **Accuracy**

±1% of reading +0.05 mS/cm

### **Operating Temperature**

0 to 50°C (32 to 122°F)

### **Dimensions**

1.70 x 12.7 cm (0.67 x 5 in.)  
with 1.9-cm (0.75-in.) MPT cable end

### **RAIN GAUGE INPUT**

For use with Hach Tipping Bucket Rain Gauge.  
Flow Meter records rainfall data in 0.01 in. increments.

### **ANALOG INPUT CHANNELS**

Up to seven additional data-logging channels record data from external source(s)  
Field assignable units  
-4.5 to +4.5 Vdc; ±0.5% full scale voltage accuracy  
0 to 20 mA; ±0.2% full scale 4-20 mA accuracy with 200 ohm impedance

### **4 - 20 MA OUTPUTS**

Up to two integral user assignable outputs  
Optically isolated  
Up to 600 ohm load per output  
0.1 % FS error  
24 Vdc - no load  
Insulation voltage between flow meter and 4-20 mA output - 2500 Vac, between the two 4-20 mA outputs - 1500 Vac

### **ALARM RELAYS**

(4) 10 amp/120 Vac or 5 amp/250 Vac form C relays  
User assignable for any internal or external data channel or event

### **MECHANICAL TOTALIZER**

6-digit non-resettable mechanical totalizer  
*Selectable units:* gal., liters, ft.<sup>3</sup>, m<sup>3</sup>, acre-ft.

### **MODEM**

14,400 baud rate  
CRC auto to check sum  
FCC approved  
Cellular compatible

### **EXPANDED MEMORY**

Increase memory from 18,432 data points to 116,736 data points

### **AC POWER BACKUP**

Provides power in the event of an AC power failure  
Internal trickle charger maintains 6 amp-hour battery

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*\*Specifications subject to change without notice.*

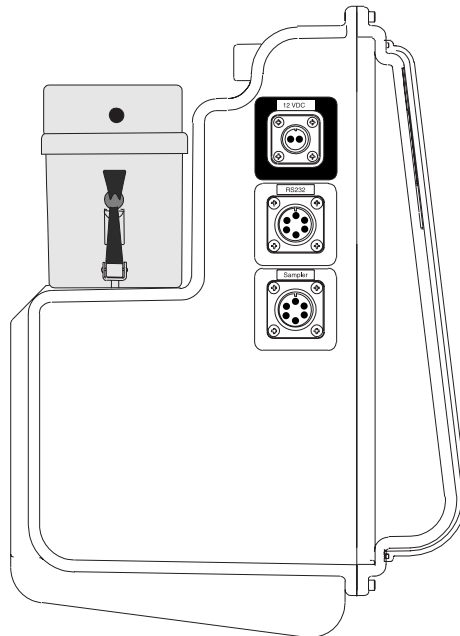
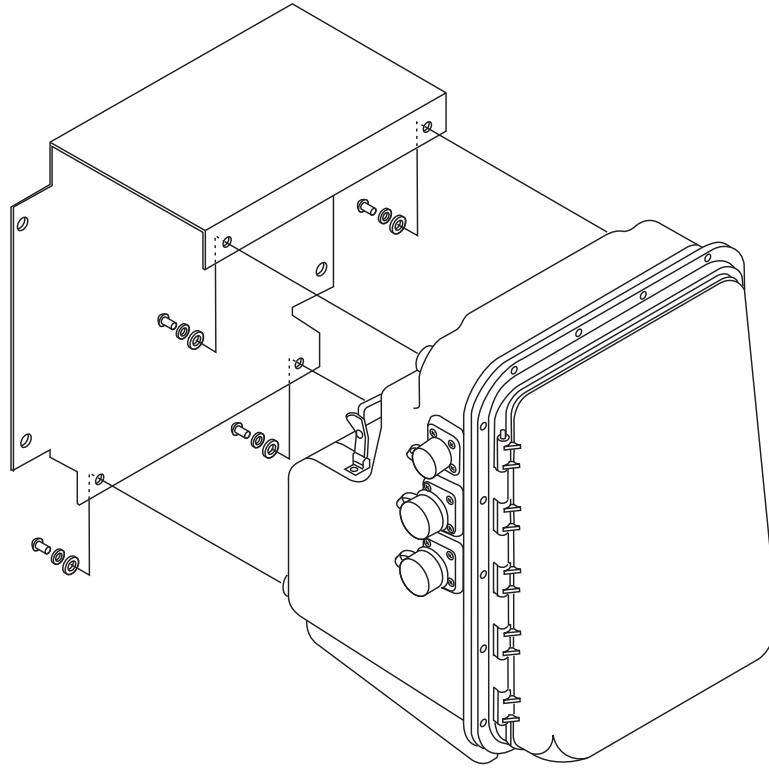
## Engineering Specifications

### Flow Meter

1. The flow meter shall operate on 12 Vdc, which is supplied by a battery or 115 Vac power converters.
2. All electrical components shall be enclosed in a NEMA 4X-6 enclosure. The enclosure shall have a continuous hinged front cover to protect the display and keypad and shall maintain NEMA 4X,6 with the cover open.
3. The enclosure shall contain desiccant and a front panel humidity indicator.
4. Current data shall be displayed on the flow meter front panel by means of an external push button on the enclosure. The meter shall not require opening of a cover to see current status.
5. The meter shall have an 8 line x 40-character backlit liquid crystal graphics display. In addition to indicating all programming steps and current status such as level, velocity and flow rate, the display shall show all logged data in field selectable tabular and graphics (x-y plot) formats.
6. All program entries shall be entered via a sealed front panel keypad, and indicated on the front panel display. The keypad and display shall meet NEMA 4X-6 standards.
7. A personal computer or any other external means shall not be required to program the flow meter or integral logger or to access data.
8. Flow meter programming/measurements:
  - a. The flow meters shall be field programmable for primary devices including:
    - i. Weirs: V-notch weirs (any angle from 22.5 to 120 degrees, compound V-notch/rectangular weirs, contracted and non-contracted rectangular weirs, trapezoidal weirs, and ThelMar weirs.
    - ii. Flumes: Parshall (1 to 144 inch), Palmer Bowlus (4 to 72 inch), trapezoidal (60 degree small, large, and extra large, 45 degree 2 and 12 inch), H. HL, and HS type flumes, and Leopold-Lagco (4 to 72 inch).
    - iii. Nozzle: California pipe method; Manning equation for round, U-channel, rectangular, and trapezoidal cross sections; power curve equation.
    - iv. Head vs. flow tables: Two tables of up to 99 (head, flow) points per table (tables may be stored in flow meter's memory and retrieved as required).
  - b. Field selectable units of measurement shall include:
    - i. Level: Inches, feet, centimeters, and meters.
    - ii. Flow rate: GPS, GPM, GPH, MGD, AFD, LPS, LPM, LPH, CFS, CFM, CFH, CFD, CMS, CMM, CMH, CMD.
    - iii. Total flow: Gallons, cubic feet, acre-feet, liters, and cubic meters.
9. Flow totalizing:
  - a. The flow meter shall have two software totalizers, one resettable and the other non-resettable.
  - b. (Optional) The meter shall include a 6-digit non-resettable electro-mechanical totalizer, protected to meet NEMA 4X, 6 standards.
10. Sampler pacing:
  - a. The flow meter shall have a 12 Vdc pulse output for pacing an automatic liquid sampler in proportion to flow, with field selectable flow volume between pulses.
  - b. The meter shall be capable of initiating a sampler on level, flow rate, and flow rate of change.
11. Integral metering devices (optional):
  - a. The meter shall be equipped with an integral pH-temperature/ORP meter. The pH meter shall have a range of 0 to 14 pH with a  $\pm 1\%$  resolution over an operating range of 0 to 176 degrees F.
  - b. The meter shall be equipped with an integral temperature meter. The temperature meter shall have an operating range of 0 to 176 degrees F. The meter shall include a platinum RTD probe in a stainless steel body with 25-foot cable.
  - c. The meter shall be equipped with an integral dissolved oxygen (DO) meter. The DO meter shall have a range of 0 to 20 mg/L (DO) with 0.01 mg/L resolution and  $\pm 0.02$  mg/L accuracy.
  - d. The meter shall be equipped with an integral conductivity meter. The conductivity meter shall have a range of 0 to 100 mS/cm with 0.01 mS/cm resolution and 1% (0.05mS/cm) of reading accuracy.
  - e. The meter shall be equipped with a rain gauge input. The sampler shall accept contact closure inputs from an external rain gauge.
  - f. The meter shall be equipped with seven external analog inputs. The first four channels shall be capable of logging a 4-20 mA current input, and the remaining three channels shall be set up to log -4.5 to +4.5 Vdc voltage input.
12. The flow meter and sensor shall be the Sigma Model 950 Permanent/Portable Open Channel Flow Meter OR Sigma Model 950 AV Optiflo Permanent/Portable Open Channel Flow Meter manufactured by Hach Company.

## Dimensions

Placement of Sigma 950 Series Permanent/Portable Open Channel Flow Meters depends on the suitability of the monitoring site. Select sites that have normalized flow and minimal turbulence. Turbulence can make it difficult to detect an average velocity in the flow stream. Obstructions, vertical drops, pipe bends, and elbows can create turbulence and affect the accuracy of measurements. Mounting options for Sigma 950 flow meters include wall mounting, suspension harness installation, or manhole rung hanger.





## Ordering Information

### Complete Flow Meter Systems

<b>3672950</b>	950 Bubbler Flow Meter; includes 25 ft. tubing	<b>2691</b>	First Set Two (2) Alarm Relays with settable trip points
<b>3680950</b>	950 Submerged Pressure Flow Meter; includes 25 ft. sensor cable	<b>2707</b>	Second Set Two (2) Alarm Relays with settable trip points
<b>3286951</b>	950 75 kHz Down-look Ultrasonic Flow Meter; includes 25 ft. sensor cable	<b>4578</b>	Modem; 14,400 baud (domestic lines only)

<b>3286952</b>	950 75 kHz In-Pipe Ultrasonic Flow Meter; includes 25 ft. sensor cable
<b>3248950</b>	950 Bubbler AV Flow Meter; includes 25 ft. of sensor cable
<b>3522950</b>	950 Submerged AV Flow Meter; includes 25 ft. of sensor cable
<b>3959952</b>	950 75k Hz Ultrasonic AV Flow Meter with In Pipe Ultrasonic and Velocity Sensors

### Integral Water Quality Options and Sensors

<b>2684</b>	Factory Installed Integral pH-Temp/ORP Sensor; includes pre-amp interface
<b>3328</b>	pH-Temperature Sensor (grounded); includes 25 ft. cable
<b>2080</b>	ORP Sensor; includes 25 ft. cable
<b>3226</b>	Factory installed DO and Conductivity Sensor; includes pre-amp interface
<b>3228</b>	Factory installed DO and EC Option with three 4-20mA Input Data Logging, includes pre-amp interface
<b>3216</b>	DO Probe Kit; includes 25 ft. cable.
<b>3225</b>	Conductivity Probe Kit; includes 25 ft. cable
<b>3222</b>	DO Probe only; includes 25 ft. cable
<b>3223</b>	Conductivity Probe only; includes 25 ft. cable

### Communication and Control Interfaces

<b>2676</b>	First 4-20 mA Output; includes 25 ft. cable
<b>2923</b>	Second 4-20 mA Output

### Sensor Mounting Hardware

<b>1361</b>	Spring Ring for 6-in. diameter pipe
<b>1362</b>	Spring Ring for 8-in. diameter pipe
<b>1363</b>	Spring Ring for 10-in. diameter pipe
<b>1364</b>	Spring Ring for 12-in. diameter pipe
<b>3263</b>	Sensor Mounting Clip; for 88000, wafer velocity, and bubbler level velocity sensors
<b>3868</b>	Portable Bracket; for in-pipe ultrasonic sensor mounting clip
<b>3875</b>	Permanent In-Pipe Ultrasonic Sensor Mounting Bracket
<b>3305</b>	Velocity Sensor Mounting Plate
<b>9574</b>	Insertion Tool; for non-confined space entry
<b>2974</b>	Permanent Wall Mount Bracket; for down-looking ultrasonic sensor
<b>2904</b>	Floor or Wall Adjustable Mounting Bracket; for down-looking ultrasonic sensor
<b>9538</b>	Tripod Mounting Bracket; for down-looking ultrasonic sensor
<b>2883</b>	Cable Straightener; for down-looking ultrasonic sensor
<b>3183</b>	Cable Grip; for down-looking ultrasonic sensor

### Cables and Interfaces

<b>1727</b>	Sampler or Flow Meter to PC Cable
<b>3358</b>	RS232 Extension Cable

### Accessories

<b>77247-00</b>	Silicon Oil; dual 50-ml pack (refills 100 sensors)
<b>77248-00</b>	Silicon Oil Refill Kit; includes dispensing tool and oil packs
<b>77256-00</b>	Oil-Filled Sub-AV Sensor Kit
<b>77300-00</b>	Retrofit Kit (converts non oil-filled to oil-filled); includes Silicon Oil Refill Kit

**At Hach, it's about learning from our customers and providing the right answers. It's more than ensuring the quality of water—it's about ensuring the quality of life. When it comes to the things that touch our lives...**

**Keep it pure.**

**Make it simple.**

**Be right.**

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**Be Right™**

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**ATTACHMENT 3-3**

Blaine Tunnel Photograph Log

**BLAINE TUNNEL PHOTOGRAPHS  
EVALUATION OF SOURCE WATER CONTROLS  
Rico-Argentine Mine Site  
Dolores County, Colorado**



1. Sandbag dam, flume, and Hach Sigma 950 downlooking ultrasonic depth sensor, looking in from out-by the "inflow" near the vertical timbers.



2. Sandbag dam with flume and Hach Sigma 950 downlooking ultrasonic depth sensor installed in-by the Humboldt Drift.



3. Downlooking ultrasonic depth sensor installed directly above the Blaine flume.

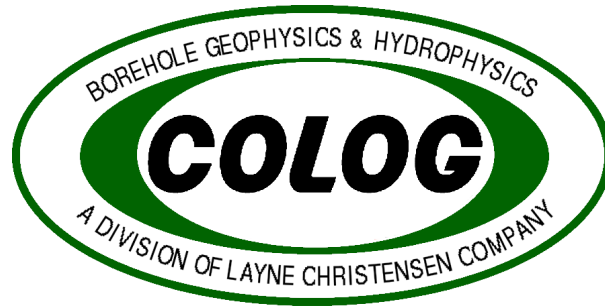


4. Blaine Tunnel pool looking in from the sandbag dam and flume, with the "flowing raise" appearing as an icicle near the back right.

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**ATTACHMENT 4**

2012 Geophysical Characterization



**Geophysical Logging Results  
Rico-Argentine Mine Site  
Dolores County, Colorado**

Prepared for  
AMEC Environment & Infrastructure, Inc.  
13 September 2012

Prepared by  
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## **I. Introduction**

In accordance with the subcontract task order No.: RICO-01, Project No.: SA11161301, Agreement No.: SD-0218-2011, Layne Christensen Company – Colog Division provided services to acquire geophysical data in the 517 Shaft at the Rico Mine Site in Rico, Colorado. Services were performed during the time period from September 4, 2012 through September 6, 2012.

517 Shaft was approximately 623 feet deep, fully timbered, in a 7'x7' in area. The opening to the shaft was about 220 horizontal feet from the portal in the abandoned 517 mine tunnel. The flooded section of the shaft was measured at a depth of approximately 452 feet and continued to a total depth of 623' as measured by the a small diameter logging probe. Specific surveillance geophysical methods included:

- A downhole video system was used to collect continuous real-time images within the 517 Shaft. As the camera was lowered downward, the collected image was toggled between axial and radial views. As the image was observed, the camera was stopped and controlled by a surface panel to capture 360° pan and tilt images as directed by an AMEC technical advisor. Depth encoding was continuously provided on the real time video image to 0.1 foot accuracy.
- A water quality monitoring device (In-Situ model 9500) was attached to the wireline above the video camera. This device logged a vertical water quality profile and included: pH, temperature, conductivity, dissolve oxygen, and oxidation-reduction potential.
- Vertical flow velocities in the flooded section were observed and recorded with a heat pulse flowmeter device. This probe was lowered to specific locations and apparent velocities were collected.
- Discrete water samples were collected from a few selected depths. Because of the limits of the wireline sampler, time constraints, and downhole water pressures, the sampling device proved to be somewhat inadequate as described in further detail in the sampling section.

Colog provided two trained, experienced technicians, equipment, materials, and supplies necessary to complete the required surveillance, including power supply, wireline, cabling, winches, monitors, tools, spare parts, etc.

In-mine support was provided by personnel from the Colorado Division of Reclamation and Mine Safety (CDRMS). CDRMS provided communication equipment. All on-site activities were carried out in level D PPE with safety constraints following MSHA, OSHA and site specific TSHASPs.

## **II. Methodology**

### **A. Temperature and Fluid Conductivity**

Geothermal gradients in the near surface earth are usually dominated by conduction, and are generally linearly increasing with depth due to the relative constancy of the thermal conductivity of earth materials. Convective heat flow within the mine shaft fluid is caused by fluid entering or leaving the mine shaft at a shaft opening or some permeable interval. Therefore, deviations from the linear thermal gradient can be attributed to fluid movement. Both the thermal gradient and fluid conductivity profile of the mine shaft fluid can be obtained with the same probe. The temperature is measured with a thermistor and the fluid conductivity is measured with a closely spaced Wenner electrical array.

Slope changes in both the temperature and fluid conductivity logs may be indicative of fluid flow between the surrounding fluids (from the formation or shaft intersections) and the mine shaft. Both responses are affected by drilling method, time since circulation, mud type or additives and well development procedures.

The fluid conductivity in the mine shaft is controlled primarily by the salinity. Therefore, salinity stratification, or the introduction of a fluid of different water quality into the mine shaft, can be observed by changes in the fluid conductivity log. Often, fluid exchange influences both the temperature and the fluid conductivity so that the response is evident in both logs.

Temperature corrected conductivity can be converted to equivalent NaCl salinity in parts per million (Bateman and Konen, 1977). A salinity profile can then be plotted which suggests the general water quality trend of the mine shaft fluid.

Fundamental assumptions and limitations inherent in these procedures are as follows:

- The mine shaft temperature log is usually the first log run in a mine shaft and, unlike virtually all other logs, is run while the probe is moving down the hole. The exception to running this probe first, however, would be if any optical measurement is to be acquired. The idea is that the logging of the temperature/conductivity probe may stir up the fluids, inhibiting the optical device.
- The recorded mine shaft temperature is only that of the fluid surrounding the probe, which may or may not be representative of the temperature in the remainder of the shaft or connecting adits.
- In most wells the geothermal gradient is considerably modified by fluid movement in the mine shaft and adjacent rocks.

### **B. Troll 9500 Multiparameter Water Quality Instrument**

For this project Colog utilized a sub-2-inch multiparameter water quality probe manufactured by In-Situ, Inc. The instrument was populated with sensors to collect Fluid Conductivity, Dissolved

Oxygen Saturation, Oxygen Saturation, pH, Fluid Temperature, and Oxidation Reduction Potential.

The ruggedized sensors utilize a wiper-free design to minimize effects in demanding environments such as high sediment loads and rapid flow rates. The 9500 sensors were factory calibrated prior to shipment and field checked before field deployment.

Stabilization criteria were set for each measured parameter and data were collected at a sample rate every 10 seconds. The Troll 9500 was attached to Colog's video cable above the camera in order to monitor conditions in the undisturbed water column within the 517 Shaft. The 9500 was setup at the surface, calibrations checked and deployed under a non-tethered condition (battery powered).

As the video camera was lowered down the shaft, depth information was obtained through the video systems digital encoding system and time tagged to feet below water surface. After the completion of the initial video survey, the water quality parameter data were downloaded to a laptop computer, quality checked, and presented on the geophysical summary plot next to flow meter data.

### C. Heat Pulse Flowmeter

The Heat Pulse Flowmeter (HFP-4293), from Mount Sopris Instruments is a high resolution device for measuring vertical fluid movement within the mine shaft. This flowmeter is based upon the proven USGS design and works on the thermal fluid tracer concept. Mine shaft fluid is heated or thermally tagged by as much as 1° F with an electrical heater grid. The flow rate is determined by measuring the time between the grid discharge and the peak of the thermal pulse of water reaching an upper or lower thermistor sensor. MSI utilizes flow concentrating diverters to direct fluid flowing in a borehole through the probe flow tube (Figure H-1). However, due to the size and shape of the mine shaft, only a small fraction of the flow could be forced through the flow tube.

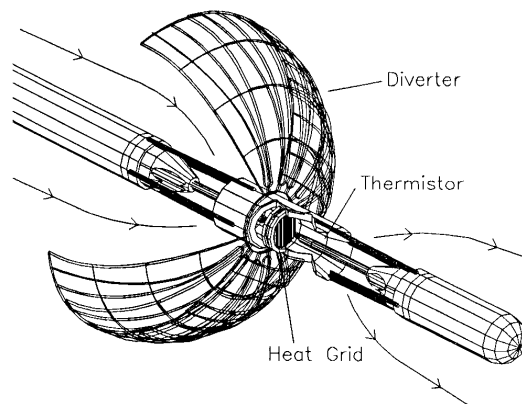


Figure H-1: Heat pulse flowmeter diverter diagram showing fluid flow

The HFP-4293 is calibrated in a flow chamber where flow rate can be controlled and measured. Values for response time are taken for a wide range of flow rates and applied in an empirical curve-fit solution (Figure H-2). The calibration coefficients are entered into the processing software to determine vertical flow rates in gallons/minute. Thermal buoyancy of the heat pulse imposes a small

asymmetry on the flow calibration so that the device is slightly less sensitive to upflow than to downflow.

Presently the HFP measures flow from 0.01 to 1.5 gallons/minute (0.038 to 5.69 liters/min) with 0.005 gpm resolution using a 1.125 inch diameter flow tube and standard multilayered flow diverter. The low end flow limit of 0.01 gpm is a function of the current calibration facility in which convective eddy currents as great as 0.01 gpm are generated by differences between water temperature in the calibration device and surrounding air. A more thermally insulated calibration chamber or smaller diameter probe flow tube could allow for significantly lower flow limit with this tool. Higher flow rates can be achieved by increasing thermistor spacing or flow tube and heating grid diameter.

In practice the HFP is run at discrete intervals within a borehole (or in this case, a mine shaft). Intervals are selected based upon review of fluid column logs (temperature, fluid resistivity, etc.), a caliper log and optimally an imaging log (video or acoustic televiewer). Flow was measured at each interval and each test repeated until at least two measurements are recorded within given tolerances. Time to collect flow data is subject to the flow rate and number of intervals tested.

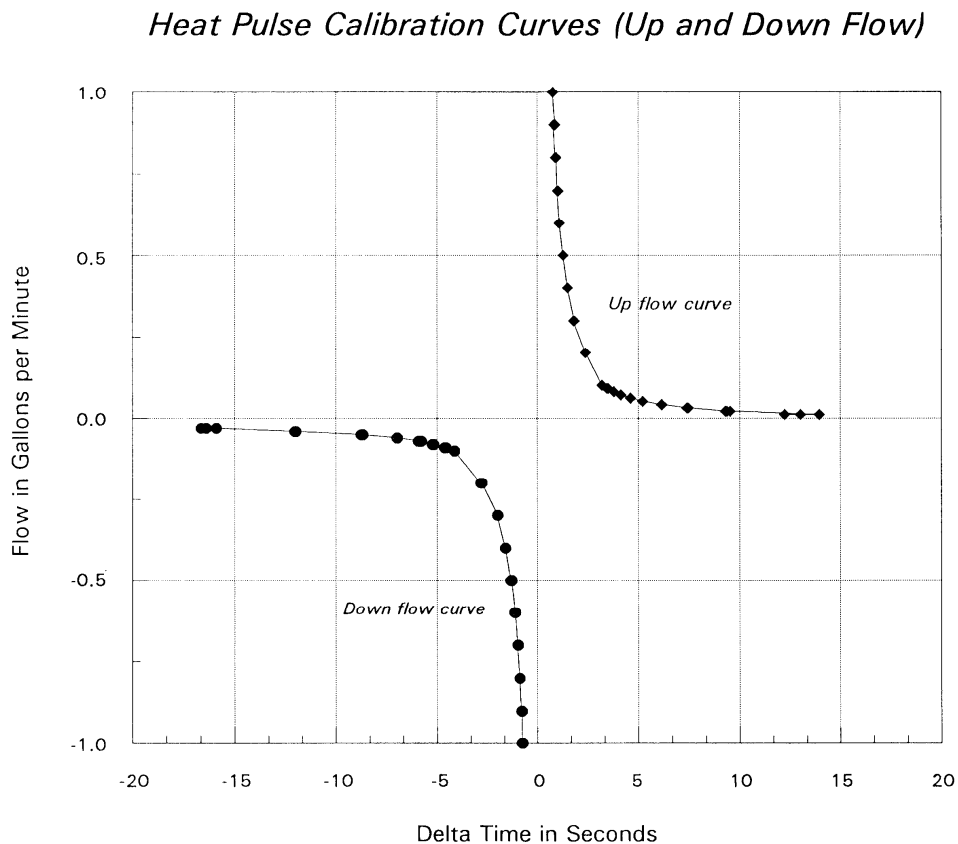


Figure H-2: Heat pulse flowmeter calibration curves used to translate response time to gpm.

A number of factors must be considered when interpreting high-resolution flow data including: 1) the effects of turbulent thermal convection and other secondary flow circulations; 2) real flow regimes are often changing with time as measurements are being made; and, 3) not all permeable intervals may be

producing vertical flow under ambient conditions. (Paillet et al, 1994)<sup>1</sup> describes these factors in detail which should be reviewed for a more thorough discussion.

Some of these factors can be minimized by using a flow concentrating diverter. More importantly, flow measurements should be collected in the same intervals under different head conditions. In areas where the flow regime is changing with time, a number of flow measurements should be measured at the same intervals over time and the resulting flow transients interpreted.

#### **D. Downhole Video Survey**

COLOG provided a downhole video survey utilizing a system manufactured by Aries Industries Company. The BT9601 dual view downhole inspection camera contains an articulating side view with 360 degree rotation. The complete stand-alone system utilizes a BT12713 camera control box and is integrated with a ¼" diameter coaxial steel armored 1500 foot cable winch.

Video surveys were recorded on HD/DVD format and viewed in real time as the color camera was lowered downward. As objects were observed the camera functionality allows for still frame focusing, sideward viewing, rotation of side image, light intensity adjustments and overall a complete control of the viewing area.

The video image is limited by artificial light illumination and water clarity. Additional submersible diving lights can be attached to the camera to provide support in large diameters and openings.

### **III. Initial Interpretation**

The fluid characterization probes were able to provide some information about the state of the water within this shaft. The flow measurements are not quantifiable, as the water was not forced through the small probe inner diameter, but was allowed to flow past the probe within the large shaft cross-section. The flow measurements do, however, demonstrate trends of flow direction and relative magnitude. Changes in flow direction are indicative of inflow or outflow and are generally supported by anomalies in the fluid quality logs.

The heat-pulse flowmeter data indicated no measureable flow at 470 feet. Above this depth, measurements indicated up-flow, and below this depth, down to 495 feet, measurements indicated down flow. This evidence suggests that at about 470 feet water is entering the shaft, and then moving away in both directions. The up-flowing water must be exiting the shaft near the static fluid level, about 452 feet. The down-flowing water appears to be exiting the shaft at about 495 feet, at which depth all vertical flow appears to have stopped. Up-flow is measured again at all stations between 495 feet and 520 feet. This suggests that water is entering the shaft at some point between 520 and 530 feet, and flowing upward, before exiting at about 495 feet. Flow, if any, at 530 feet,

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<sup>1</sup> Paillet, Crowder and Hess, 1994, High-Resolution Flowmeter Logging - A Unique Combination of Borehole Geophysics and Hydraulics: Part II - Borehole Applications With the Heat-Pulse Flowmeter, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Boston, Massachusetts, pages 381-404.



and all deeper stations, is not measureable. The increase in the down-flow magnitude between the 475 foot and 480 foot stations suggests inflow between these stations. Likewise, the decreases in the down-flow magnitude between the 480 foot, 485 foot, and 490 foot stations suggests outflow throughout this interval.

The fluid conductivity log registers anomalies at 473 feet and at 497 feet, correlating with the in and out flow suggested by the flow data. The anomaly at 497 feet is corroborated by the dissolved oxygen logs, which show a drop in the oxygen level at this depth. Similarly, there is a slight pH shift at 497 feet. The fluid conductivity is noticeably reduced below 522 feet. This depth corresponds with the obstruction encountered by the video camera. Please note that the In-Situ probe was attached to the video camera, and was also unable to pass the obstruction. Temperature data suggest two distinct environments, one above 539 feet, where the temperature is relatively constant, and one below 539 feet, where the temperature gradually decreases with depth. The broad slope changes below 539 feet are consistent with very slow stratification, as would be expected in a non-flowing environment.

## **APPENDIX A**

### **Geophysical Log Plots**



# Geophysical Summary Plot

COMPANY: AMEC

PROJECT: Rico-Argentine Mine

DATE LOGGED: 5 Sept. 2012

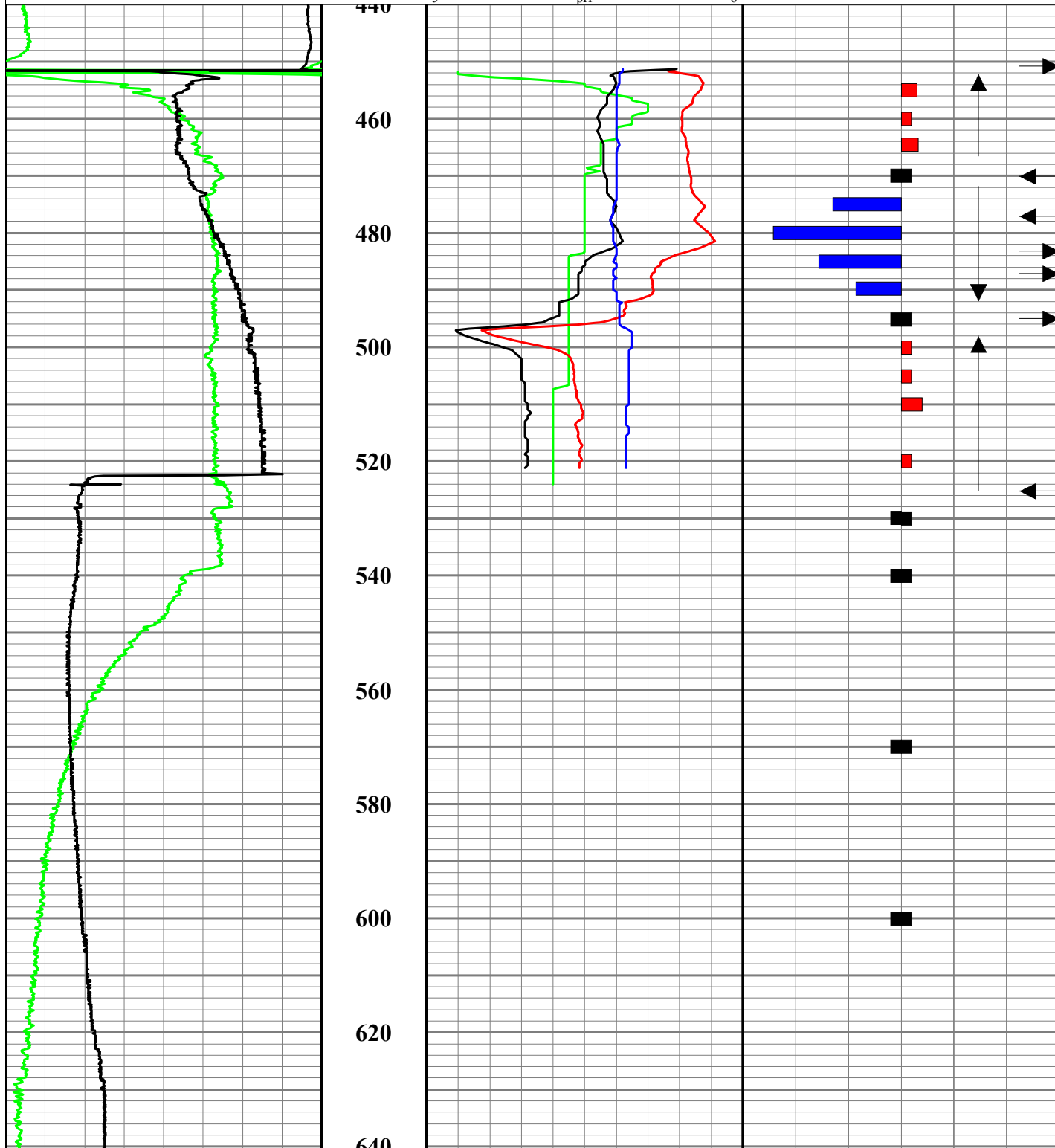
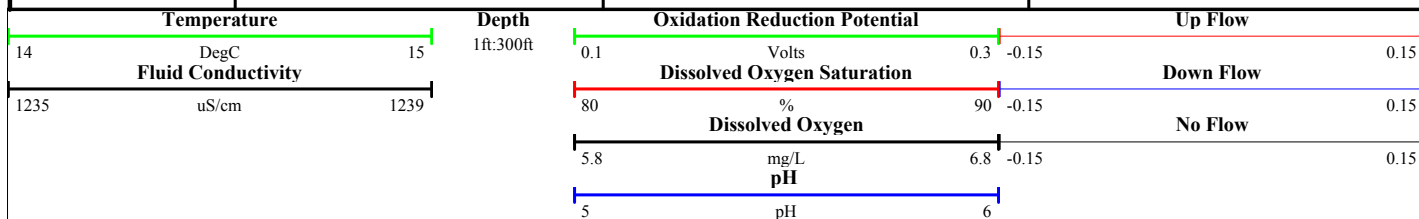
WELL: Shaft 517

COLOG Main Office

810 Quail Street, Suite E, Lakewood, CO 80215

Phone: (303) 279-0171, Fax: (303) 278-0135

www.colog.com



## **APPENDIX B**

### **Equipment Specifications**



## TROLL® 9500 Multiparameter Instrument



The powerful, portable TROLL 9500 Water Quality Instrument is designed for groundwater and surface water monitoring. The unit houses up to nine water quality sensors, internal power, and optional data logger.

### Lower Total Cost of Ownership

- Instrument saves time and money by offering long-lasting internal power, automated low-flow sampling, and telemetry accessibility.
- Field-proven sensors and antifouling system reduce maintenance and site visits.
- Intuitive Win-Situ® 4 Software and Flow-Sense Software improve efficiency by simplifying data collection and management.

### Reliable, Accurate Operation

- Instrument operates in fresh, waste, and marine waters.
- Instrument offers proven performance. Rigorous third-party testing shows that the TROLL 9500 delivers consistent results.
- Sensors are factory calibrated with NIST®-traceable standards (where applicable).

### Outstanding Customer Service

- Free, 24/7 technical support
- Seven-day service for maintenance and calibration (U.S.A. only)

### Logging Models

- **LTS:** LTS stands for “Level, Temperature, and one additional Sensor,” such as conductivity, dissolved oxygen (DO), or pH.
- **Professional:** This unit offers the highest value for most applications. Instrument allows for several sensors, including conductivity/salinity, DO, ORP, pH, temperature, or depth.
- **Professional XP:** The most capable TROLL 9500 offers features available on the Professional and supports XP or “Extended Parameter” sensors—turbidity, ammonium, chloride, or nitrate.

### Non-Logging Models

- **Profiler:** Ideal for sampling or vertical profiling, this unit is similar to the Professional, but does not include memory or logging capabilities. Data can be logged to a RuggedReader® Handheld PC or laptop.
- **Profiler XP:** This unit offers the same features as the Profiler with the option to use XP sensors.

## Applications

- Coastal deployments—estuaries and wetlands
- Environmental monitoring and spot checking
- Low-flow groundwater sampling
- Remediation and mine water monitoring
- Stormwater management
- Vertical profiling



# TROLL® 9500 Water Quality Sensors

## Customizable for Your Application



Choose from several field-ready sensors. The selected sensor set will determine the diameter of the TROLL 9500—sub-2 inch or sub-4 inch.

- **Barometric pressure:** Use this sensor to compensate water level and DO values.
- **Conductivity:** Characterize water quality in actual conductivity, specific conductivity, salinity, TDS, or specific gravity.
- **DO:** Choose from the optical Rugged Dissolved Oxygen (RDO®) Sensor or Clark cell.
- **Level/Pressure:** Non-vented and vented sensors are available for several ranges.
- **Nutrients:** Choose from ion-selective electrodes for ammonium, chloride, or nitrate.
- **pH or pH/ORP:** Extend field use with durable sensors. The re-buildable pH sensor outlasts traditional sensors.
- **Temperature:** Compensate conductivity, DO, pH, and nutrient data with this fast, accurate sensor.
- **Turbidity or Turbidity/Level:** Comply with ISO standards. The turbidity sensor uses ISO 7027 method. Optional wiper is available for high-fouling sites or for lengthy deployments.



## Optical RDO Sensor

Breakthrough RDO technology surpasses Clark cell performance by eliminating hydration effects, membranes, electrolyte solution, and stirring.

- **Rugged performance:** Wiper-free design excels in demanding environments. Abrasion-resistant foil withstands fouling, high sediment loads, and rapid flow rates. No photobleaching effects.
- **Automatic setup:** RDO Cap with pre-loaded calibration coefficients simplifies setup and eliminates programming errors.
- **Accurate results:** Operates with low drift over long-term deployments. Excels in hypoxic conditions. Responds quickly and maintains stable response.
- **Long-lasting calibration:** Deploys for several months if sensor fouling is minimal and if the foil is not damaged or removed.
- **Minimal interferences:** Sensor is unaffected by sulfides, sulfates, hydrogen sulfide, carbon dioxide, ammonia, pH, or chloride.
- **Fast response:** Ideal for vertical profiling and dynamically changing conditions.



## TROLL 9500 Accessories



### TROLL® Shield Antifouling System

The TROLL Shield Guard slows biofouling on TROLL 9500 sensors. The guard extends instrument deployments in coastal environments and at high-fouling sites by up to six weeks.

### DO Field Bubbler Kit

For accurate results, use the DO Bubbler Kit for air-saturated water calibrations. The kit reduces time spent on calibration setup.

### Calibration Solutions

From easy-to-use Quick Cal Solution to NIST®-traceable standards, In-Situ supplies calibration solutions required to get accurate results. Call for details or visit [www.in-situ.com](http://www.in-situ.com).

### RuggedCable® Systems, Reels, & Well Accessories

RuggedCable Systems endure harsh environments and last for years. Titanium twist-lock connectors and Kellems® grip are included. Vented or non-vented cable is available in either Tefzel® or polyurethane. Order customized lengths up to 1,219 m (4,000 ft). Steel or plastic reels make deployment of long cables manageable. Ask us about well-docking accessories.



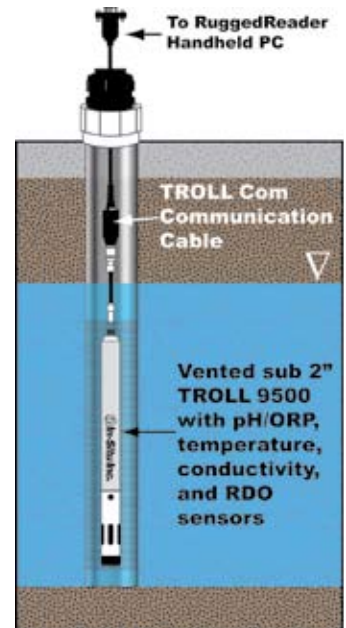
# Real-Time Monitoring for Remediation



## Conduct ISCO, ISCR, Biosparging, Air Sparging & More

The TROLL® 9500 Instrument supports real-time measurement of performance indicators, which allows for a dynamic work strategy per the EPA Triad Approach to site remediation. You can adapt to changing conditions as new data becomes available. This allows you to complete projects more quickly and at a lower cost than when using traditional approaches. The TROLL 9500:

- Features sub-2 inch configuration for key parameters: DO with the RDO® Sensor, conductivity, pH/ORP, temperature, and barometric pressure
- Deploys in harsh conditions. The corrosion-resistant housing is suitable for many remediation applications.
- Reduces grab sampling and labor costs while improving safety when working with treatment chemicals
- Improves performance and reduces maintenance when deployed with the RDO Sensor
- Connects to the TROLL® Link Telemetry System for remote access and external power



## TROLL 9500 Low-Flow Sampling System

You can use the TROLL 9500 System with Flow-Sense Software to conduct low-flow purging and sampling. You will collect representative samples, minimize contaminant volatilization, and reduce hazardous waste disposal. To improve efficiency in the field, the system:

- Automates collection of well and pumping information
- Monitors and records stabilization of key water quality parameters
- Automatically generates defensible calibration and sample reports that conform to federal and regional regulations
- Eliminates transcription time and errors

### Automated Test Setup

Flow-Sense Software retains all project information—well data, pump performance specifics, tubing details, pumping rate, stabilized drawdown, and parameter stabilization criteria. You can quickly access site information at subsequent sampling events without reentering data.

Win-Situ® Sync Software automatically copies well records and data between a computer and a RuggedReader® Handheld PC.

### Automated Data Collection

Stabilization criteria are set for each monitored parameter. Data collection intervals are defined by time or pumped volumes. During sampling, software calculates and displays variance and targets for each parameter. Data is logged at pre-determined intervals and stabilization is achieved when readings meet variation criteria. In addition, you can view data numerically or graphically.



### Automated Test Report Generation

After stabilization, stored data can be exported into Excel®. Flow-Sense Software automatically generates full calibration and sample reports that conform to federal and regional regulations. To save time, simply reuse templates at subsequent sampling events.

# TROLL® 9500 Multiparameter Instrument

General		TROLL 9500 Water Quality Instrument			
Operating temp.	-5 to 50° C (23 to 122° F)				
Storage temp.	-40 to 65° C (-40 to 140° F)				
Dimensions & weight	4.7 cm (1.85 in) OD x 55.25 cm (21.75 in). With twist-lock hanger: 56.52 cm (22.25 in). Restrictor: 8.9 cm (3.5 in) OD x 21 cm (8.25 in) long; 1.9 kg (4.2 lbs)				
Wetted materials	PVC, 316L stainless steel, titanium, Acetal, Viton®, nylon. Cable: Tefzel® or polyurethane				
Water tightness rating	IP68 with all sensors and cable attached. Battery compartment: IP67 without the battery cover or cable attached				
Output options	RS485/RS232; SDI-12 (optional with SDI-12 adapter); ASCII streaming mode or binary command				
Power	External: 9-16 VDC (optional). Internal: 2 user-replaceable D batteries (use either alkaline or matched pair of lithium). Use only Saft LSH-20 3.6V lithium D cells. Use of any other battery will void the warranty.				
Logging					
Data logging	16 programmable tests (defined, scheduled to run, or stored). Logging modes: Linear, Linear Average, Event				
Memory	4 MB (222,000 data records¹)				
Standard Sensors	Accuracy	Range	Depth Rating	Response Time	Methodology
Barometric pressure	±0.3% FS	16.5 psia	Meets highest rating	< 30 sec per 30 m (100 ft) of cable	Silicon strain gauge
Level, Depth, Pressure	±0.1% FS or better Sensor accuracy: -5 to 50° C	15, 30, 100, or 300 psi	<i>Non-vented</i> 30 psia: 10.90 m (35.76 ft) 100 psia: 60.11 m (197.2 ft) 300 psia: 200.7 m (658.6 ft) <i>Vented</i> 15 psig: 10.55 m (34.61 ft) 30 psig: 21.10 m (69.21 ft) 100 psig: 70.32 m (230.7 ft) 300 psig: 211.0 m (692.1 ft)	Instantaneous in thermal equilibrium	Silicon strain gauge (non-vented or vented)
Conductivity	Low: ±0.5% or 2 µS/cm High: ±0.5% + 2 µS/cm	Low: 5 to 20,000 µS/cm High²: 150 to 112,000 µS/cm	Low: Meets highest rating High: Meets highest rating	Low: Instantaneous High: Instantaneous	Std. Methods 2510, EPA 120.1 Std. Methods 2510, EPA 120.1
Dissolved oxygen RDO® Sensor³	±0.1 mg/L ±0.2 mg/L ±10% of reading	0 to 8 mg/L 8 to 20 mg/L 20 to 50 mg/L	150 psi from 0 to 50° C 300 psi @ 25° C	T90: < 45 sec. T95: < 60 sec. T90: < 45 sec. T95: < 60 sec. T90: < 45 sec. T95: < 60 sec.	<i>EPA-approved In-Situ Methods⁴</i> 1002-8-2009, 1003-8-2009, 1004-8-2009
Clark cell electrode	±0.2 mg/L	0 to 20 mg/L; 0 to 200% saturation	246 m (807 ft)	1-mil membrane: 1-2 min @ 25° C 2-mil membrane: 90 sec to 3 min	Std. Methods 4500-O G, EPA 360.1
pH (single)⁵ or pH/ORP (combo)⁵	pH: ±0.1 pH unit ORP: ±5.0 mV	pH: 0 to 12 pH units ORP: ±1400 mV	pH: 211 m (692 ft) pH/ORP: 211 m (692 ft)	pH: < 15 sec, pH 7 to pH 4 ORP: < 15 sec	pH: Std. Methods 4500-H⁺, EPA 150.2 ORP: Std. Methods 2580
Temperature	±0.1° C	-5 to 50° C (23 to 122° F)	Meets highest rating	< 30 sec	EPA 170.1
Extended Parameter (XP) Sensors					
Ammonium (NH₄⁺)	±10%	0.14 to 14,000 ppm N	14 m (46 ft)	T98: < 60 sec, 1.4 to 14 ppm N	Std. Methods 4500-NH₃ D, EPA 350.3
Chloride (Cl⁻)	±15%	0.35 to 35,500 ppm Cl	70 m (231 ft)	T98: < 60 sec, 3.54 to 35.45 ppm Cl	Std. Methods 4500-Cl⁻ D
Nitrate (NO₃⁻)	±10%	0.14 to 14,000 ppm N	14 m (46 ft)	T98: < 60 sec, 1.4 to 14 ppm N	Std. Methods 4500-NO₃ D
Turbidity	±5% or 2 NTU/FNU	0 to 2,000 NTU/FNU	105 m (346 ft)	Instantaneous (5 sec for first reading)	ISO 7027
Warranty	TROLL 9500 and all sensors (excluding RDO & ISE sensors) come with a 1-year warranty. RDO Sensor: 3-year warranty. ISE sensors: 90-day warranty. RuggedCable® System: 2-year warranty.				
Notes	¹A single data record includes time stamp, temperature, RDO, pH, and conductivity logged in Linear or Linear Average mode. ²Full operating range: 70 to 200,000 µS/cm. ³Full operating range: 0 to 50 mg/L. ⁴EPA-approved; call for details or visit <a href="http://www.in-situ.com">www.in-situ.com</a> . ⁵ pH sensor and pH/ORP sensor temperature range: 0 to 50° C.				

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**Call to purchase or rent—[www.in-situ.com](http://www.in-situ.com)**

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1-800-446-7488 (toll-free in U.S.A. and Canada)

1-970-498-1500 (U.S.A. and international)

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# 2FSA-1000 Discrete Sampler

## Specifications

**Name or Model:** 2FSA-1000 1-liter Sampler Tool

**General Description:** The 2FSA-1000 is a 1-liter discrete sampler tool that connects to any MSI logging system. 2-liter models are available also. Any gases captured at depth can be released into customer-supplied plumbing at the surface.

**Length :** 234 cm (80")

**Diameter :** 40mm (1.6"), 1-liter tool

**Pressure Rating:** 600 Bar (10,000 PSI)

**Weight :** 12.3 Kg (27 lbs), 1-liter tool

**Operating Temperature:** up to 80 C

**Sensor:** user-controlled solenoid piston

**Accuracy :** n/a

**Resolution:** n/a

### Field Applications:

- ▶ Heavy duty, high-torque motor with ball screw drive
- ▶ Pressurized sample size easily changed by using different length or OD of reservoir housing.
- ▶ Bottom sub encloses sample transfer valve.
- ▶ Customer can order reservoir capacities of 1 or 2 liters. Larger capacities available.

# 2WQA-1000, 2PFA-1000, 2SFA-1000

**Name or Model:** 2WQA-100, Temperature-Fluid Resistivity

**General Description:** The 2PFA-1000, combination temperature/fluid resistivity probe, provides valuable information for the hydrologist and groundwater scientist concerning borehole fluid character and flow. The 2PFA-1000 is configured as a "Poly" probe, with a quick-connect probe top that allows it to be easily attached to either a Poly gamma probe or fitted with a probe top adapter to run in stand alone mode. Other versions of this probe, designated 2WQA-1000, 2WQB-1000, or 2WQC-1000 are stand-alone probes with respectively, a Mount Sopris single conductor, four-conductor, or GO/I four-conductor top. Finally, the measurements are also available as a factory-mounted sub that is mounted permanently to the bottom of the 2PEA-1000, Poly Electric (2SFA-1000) or 2PCA-1000, Poly Caliper (2SFB-1000) or 2CAA-1000 Caliper (2SFB-1000) probes. The 2PFA-1000 and its various configurations include a seven electrode mirrored Wenner array for measuring borehole fluid resistivity and a temperature sensor based on a fast response semiconductor device whose output voltage changes linearly with temperature. The resistivity array is an internal cylindrical array open at the bottom of the probe. Borehole fluid passes by the array as the probe is lowered in the hole. The array is completely shielded from the outside borehole, so that only fluid resistivity is measured. The temperature sensor is located at the top of the sensor body, in the center of the three exit ports where the borehole fluid returns to the well bore. The "K" factor for the Wenner array is empirically derived, and is approximately 12, when checked for fluid resistivity ranging from 3 to 78 ohmmeters.

**Length :** 2PFA: 52 cm (20.5")

**Diameter :** 39mm (1.5")

**Pressure Rating:** 200 Bar (3000 PSI)

**Weight :** 1.4 Kg (3.1 lbs)

**Operating Temperature:** 80 C (176 F)

**Sensor:** 7-electrode mirrored Wenner array & fast-response semi-cond. for Temperature

**Accuracy :** Better than 1% both sensors

**Resolution:** FR: 0.05%. Temp.: 0.01 C

**Field Applications:** Temperature-Fluid Resistivity measurements are used in water quality studies, fracture characterization work, and geothermal gradient mapping.



## BT9601

**BT9601 DUAL VIEWING DOWNHOLE INSPECTION COLOR  
WITH ARTICULATING SIDE VIEW AND ADDITIONAL LED LIGHTING**



### **CAMERA SPECIFICATIONS:**

- NTSC Format
- Horizontal resolution of 480 TV lines
- Effective Picture Element 768(H) X 494(V)
- Hermetically sealed and charged with up to 15 psi of nitrogen gas
- 2.2 mm lens with a maximum field of view of 92.6 degrees
- Stainless steel watertight underwater housing
- Weight less than 19 lbs
- FSK/digital control technology
- Internal diagnostic check system with on-screen display
- Minimum illumination of 1 lux @ f1.2
- 3.5 inch maximum outside diameter
- 22 inches long
- Color Camera Module
- Maximum power consumption – 150Watts
- Pressure rated to 2,500 psi.

# BT12713

## Single Conductor Portable Camera Control Unit

BT12713 will control all CCV made cameras, as well as some competitors. Voltages range from 80 VDC to 200 VDC. The control unit will operate cameras through 1,500 feet of ¼ inch coaxial cable. The LCD meter will alert you to any impending communication problems. Additional video output and microphone is included. A built in fan helps cool the electronics. The additional on-screen counter module allows for a 1 pulse, 10 pulse, or a greater than 128 pulse per revolution 5 VDC encoder. All connection cables are included, as well as a CV93672 desktop control box.



### CONTROL UNIT FEATURES:

1. Dual View or Single view camera operation
2. Dimensions: 10.5H X 10.5W X 17L
3. Economically priced
4. Electronically configured to operate up to 1500' of cable length
5. On-screen depth footage
6. Voice over recording (microphone)
7. Additional Video/Audio outputs available

Insert DVD of the 2012 downhole  
video with hard copies.

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**ATTACHMENT 5**

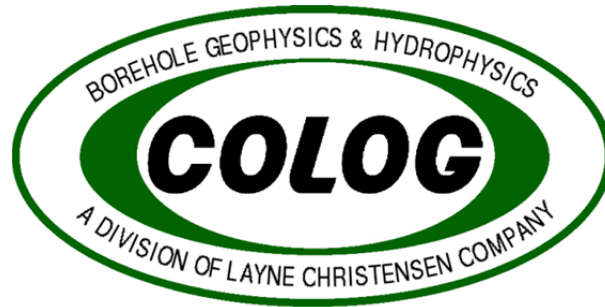
2013 Geophysical Characterization

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**ATTACHMENT 5-1**

2013 Geophysical Logging Results





**Geophysical Logging Results  
Rico-Argentine Mine Site  
Dolores County, Colorado**

Prepared for  
AMEC Environment & Infrastructure, Inc.  
6 December 2013

Prepared by  
Layne Christensen Company – Colog Division  
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Phone: (303) 279-0171 Fax: (303) 278-0135

## I. Introduction

In accordance with the subcontract task order No.: C013100613, Project No.: SA11161313, Agreement No.: SD-0218-2011, Layne Christensen Company – Colog Division (Colog) provided services to acquire geophysical data in the 517 Shaft (mine shaft) at the Rico-Argentine Mine Site in Rico, Colorado (site). Services were performed during the time period from May 15 through June 18, 2013.

The 517 Shaft was found to be fully timbered and approximately seven feet by seven feet in area. The opening to the shaft was about 220 horizontal feet from the portal of the 517 Shaft Access Tunnel. The flooded section of the mine shaft was measured at a depth of approximately 453 feet below the shaft collar<sup>1</sup> (i.e. below ground surface) and continued to a total depth of 623 feet, as measured by a small diameter logging probe. Specific surveillance geophysical methods included the following:

- A water quality monitoring probe (Mount Sopris model 2ISA-1000) logged a vertical water quality profile and included: pH, temperature, conductivity, dissolved oxygen, and oxidation-reduction potential (ORP).
- A water quality monitoring device (In-Situ model TROLL 9500) was attached to the wireline above the Sonar head. This device logged a vertical water quality profile and included: pH, temperature, conductivity, and ORP.
- Vertical flow velocities in the flooded section were observed and recorded with a Corehole Dynamic Flowmeter probe. This probe was lowered to specific locations and apparent velocities were collected.
- Horizontal flow velocities in the flooded section were observed and recorded with a Colloidal Borescope Flowmeter probe. This probe was lowered to specific locations and apparent velocities and directions were collected.
- Discrete water samples were collected from several selected depths with an air-powered submersible pump (Bennett model 180-6). The pump was lowered to specific locations and water samples were collected from the outflow tube, at the surface. All tubing was purged, with the intake at the specified depth, before each sample.
- Acoustic imaging was performed with a horizontal scanning sonar head (Imagenex 881A). The sonar head was raised from the deepest accessible point, 537.2 feet, to the ambient fluid level, 453.4 feet, at a constant rate, while the head was rotating. Lower depths were not accessible by the sonar head due to collapsed timbers encountered within the mine shaft.
- A downhole video system was used to collect continuous real-time images within the 517 Shaft. As the camera was lowered downward, the collected image was toggled between axial and radial views. As the image was observed, the camera was stopped and controlled by a surface panel to capture 360° pan and tilt images as directed by an

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<sup>1</sup> All depths presented herein are measured as feet below the 517 Shaft collar.

AMEC technical advisor. Depth encoding was continuously provided on the real time video image to 0.1 foot accuracy.

Colog provided two trained, experienced technicians, equipment, materials, and supplies necessary to complete the required services, including power supply, wireline, cabling, winches, monitors, compressor, tools, and spare parts.

In-mine support and communication were provided by personnel from the Colorado Division of Reclamation, Mining, and Safety (CDRMS). All on-site activities were carried out in level D personal protective equipment (PPE), with safety constraints following task specific health and safety plans (TSHASPs).



Geophysical logging trucks staged outside the 517 Shaft Access Tunnel portal.





Blaine Tunnel portal.

## II. Methodology

### A. Water Quality Probe

For measuring in-situ fluid properties, Colog utilized the Mount Sopris Instruments 2IFA-1000 water quality probe. The probe integrates the Ocean Seven 303 fluid sensor package, from Idronaut, in a  $1\frac{5}{8}$  inch down-hole package that can communicate with the standard Mount Sopris Matrix and MGX-II logging platforms. Pressure, temperature, fluid electrical conductivity, pH, dissolved oxygen, and ORP measurements are made at frequent intervals, as small as 0.1 foot, as the probe is trolled slowly down through the fluid column. Salinity can be calculated according to the United Nations Educational, Scientific and Cultural Organization (UNESCO) Practical Salinity Scale of 1978, and dissolved oxygen concentrations can be calculated from oxygen percent using the UNESCO 1986 formula.

<b>Sensor Specifications:</b>			
<b>Parameter</b>	<b>Range</b>	<b>Accuracy</b>	<b>Resolution</b>
Pressure	0-1500 dbar	0.25% FS	0.1 dbar
Temperature	-1 - 49°C	0.02°C	0.004°C
Conductivity (Sea Wtr)	0 – 62 mS/cm	0.02 mS/cm	0.004 mS/cm
Conductivity (Fr Wtr)	0 – 6200 µS/cm	2 µS/cm	0.04 µS/cm
Oxygen	0 50 ppm	0.1 ppm	0.01 ppm
pH	0 – 14 pH	0.05	0.01
Redox	-1000 - +1000mV	10 mV	1mV

Sensor Specifications for the Ocean Seven 303 sensor package.

Geothermal gradients in the near surface earth are usually dominated by conduction and are generally linearly increasing with depth due to the relative constancy of the thermal conductivity of earth materials. Convective heat flow within the mine shaft fluid is caused by fluid entering or leaving the mine shaft at an opening or some permeable interval. Therefore, deviations from the linear thermal gradient can be attributed to fluid movement. Both the thermal gradient and fluid conductivity profile of the mine shaft fluid can be obtained with the same probe. The temperature is measured with a thermistor and the fluid conductivity is measured with a closely spaced Wenner electrical array.

Slope changes in both the temperature and fluid conductivity logs may be indicative of fluid flow between the surrounding fluids (from the formation or mine tunnel intersections) and the mine shaft.

The fluid conductivity in the mine shaft is controlled primarily by the salinity. Therefore, salinity stratification, or the introduction of a fluid of different water quality into the mine shaft, can be observed by changes in the fluid conductivity log. Often, fluid exchange influences both the temperature and the fluid conductivity so that the response is evident in both logs.

Temperature corrected conductivity can be converted to equivalent NaCl salinity in parts per million (Bateman and Konen, 1977). A salinity profile can then be plotted to indicate the general water quality trend of the mine shaft fluid. Fundamental assumptions and limitations inherent in these procedures are as follows:

- The temperature log is usually the first log run and, unlike virtually all other logs, is run while the probe is moving downward. The exception to running this probe first, however, would be if any optical measurement is to be acquired. The idea is that the logging of the temperature/conductivity probe may stir up the fluids, inhibiting the optical device.
- The recorded mine shaft temperature is only that of the fluid surrounding the probe, which may or may not be representative of the temperature in the remainder of the mine shaft or connecting tunnels.
- Typically the geothermal gradient is considerably modified by fluid movement in the mine shaft and adjacent rocks.

## **B. Troll 9500 Multiparameter Water Quality Instrument**



A sub-two inch multiparameter water quality sonde (Troll 9500), manufactured by In-Situ, Inc, was used to collect duplicate measurements of mine shaft fluid conductivity, pH, temperature, and ORP. The ruggedized sensors utilize a wiper-free design to minimize effects in demanding environments such as high sediment loads and rapid flow rates. The sensors were factory calibrated prior to shipment and field calibrated prior to deployment.

Stabilization criteria were set for each measured parameter, and data were collected at a sample rate of 10 seconds. The Troll 9500 was attached to Colog's video cable above the camera in order to monitor conditions in the undisturbed water column within the 517 Shaft. As the video camera was lowered down the mine shaft, depth information was obtained through both the Troll 9500's pressure transducer probe and the video system's digital encoding system and time tagged to feet below water surface. After the completion of the initial video survey, the water quality parameter data were downloaded to a laptop computer and quality checked. These data are presented on the Geophysical Summary Plot (Attachment A) next to flow meter data.

The data collected in 2012, replotted to accurately indicate water surface depth, is included as Attachment B for reference. For a discussion of that data, please see the report provided in September 2012.

### **C. Corehole Dynamic Flowmeter**

Colog's Corehole Dynamic Flowmeter (CDFM) is a high resolution device for measuring vertical fluid movement within a borehole. The flowmeter measures flow rates using the principal of Faraday's Law of Induction, and consists of a hollow cylinder housing an electromagnet and two electrodes, located 180 degrees apart and 90 degrees to the magnetic field. The voltage induced by a conductor (water), moving at right-angles through the magnetic field, is directly proportional to the velocity of the conductor.

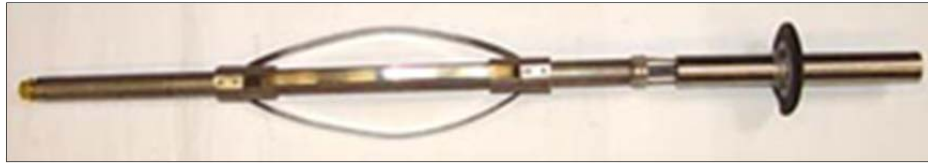
The CDFM measures flow from 0.02 to 10 gallons per minute (gpm) (0.05 to 40 liters per minute) through the 0.91 inch diameter flow tube and standard multilayered flow diverter. Greater flow rates may be calculated by allowing a portion of the flow to move around the flowmeter or diverters, requiring estimates on the proportion of flow through, to flow around, the flowmeter, using known casing or corehole diameters.

The CDFM was run at discrete intervals within the mine shaft. Intervals were selected based upon a review of the measured water quality parameters (temperature, pH, conductivity, ORP and a video log). After a stabilization period of approximately five minutes, fluid velocity was measured at each station several times, until repeatable results were obtained.

A number of factors must be considered when interpreting high-resolution flow data including: 1) the effect of the irregular mine shaft on the flow regime, including adjoining tunnels and voids; 2) the effects of turbulent thermal convection and other secondary flow circulations; 3) real flow regimes are often changing with time as measurements are being made; and, 4) not all permeable intervals may be producing vertical flow under ambient conditions.

In a round well or borehole, some of these factors can be minimized by using a flow concentrating diverter and by locating the diverter in a portion of the borehole that is not fractured or rugose (by analyzing the caliper or a borehole imaging log). Due to the geometry of the mine shaft, though a

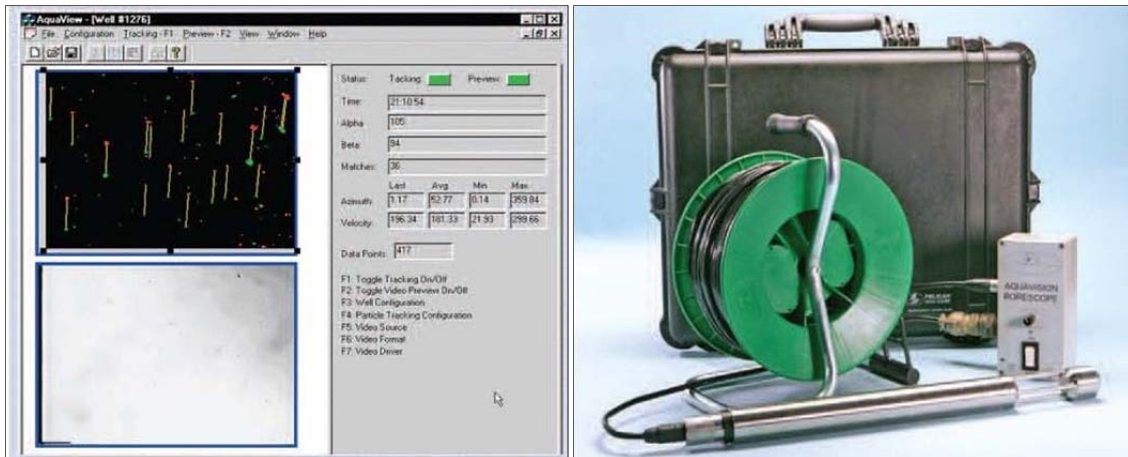
diverter was used, most of the fluid movement within the shaft would have been around the CDFM. Efforts were made to suspend the CDFM in the center of the mine shaft, but the actual lateral placement of the CDFM could not be verified.



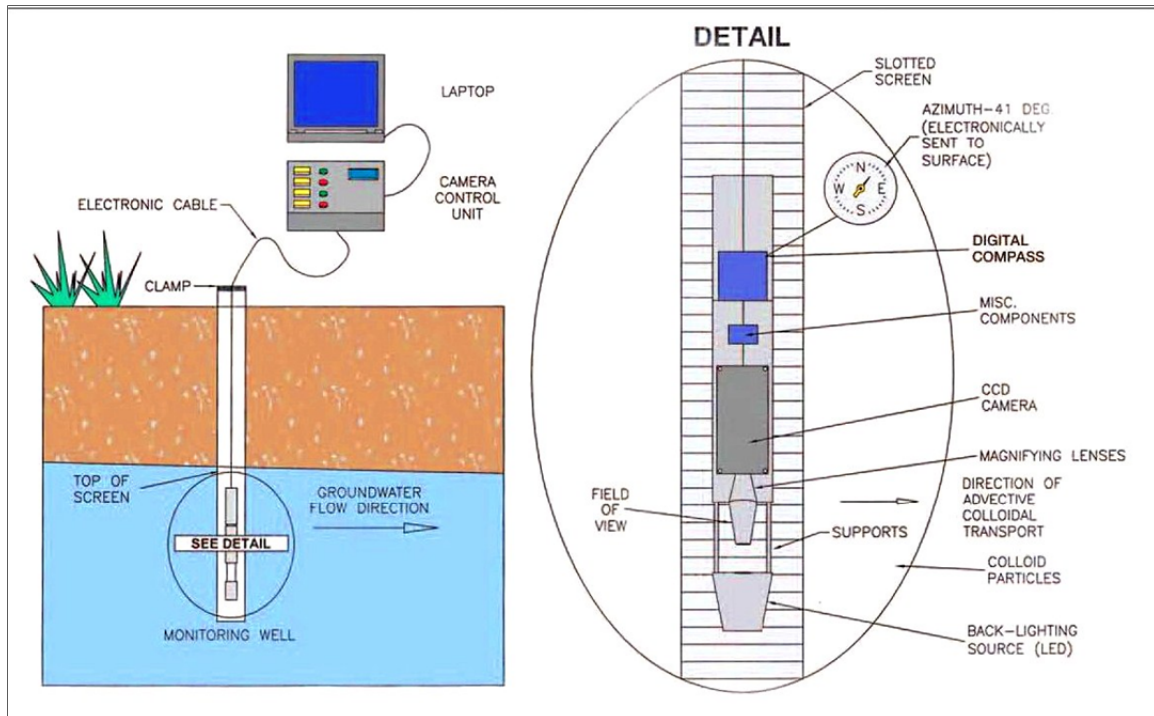
CDFM shown with flow diverters and centralizer.

#### D. Colloidal Borescope Flowmeter

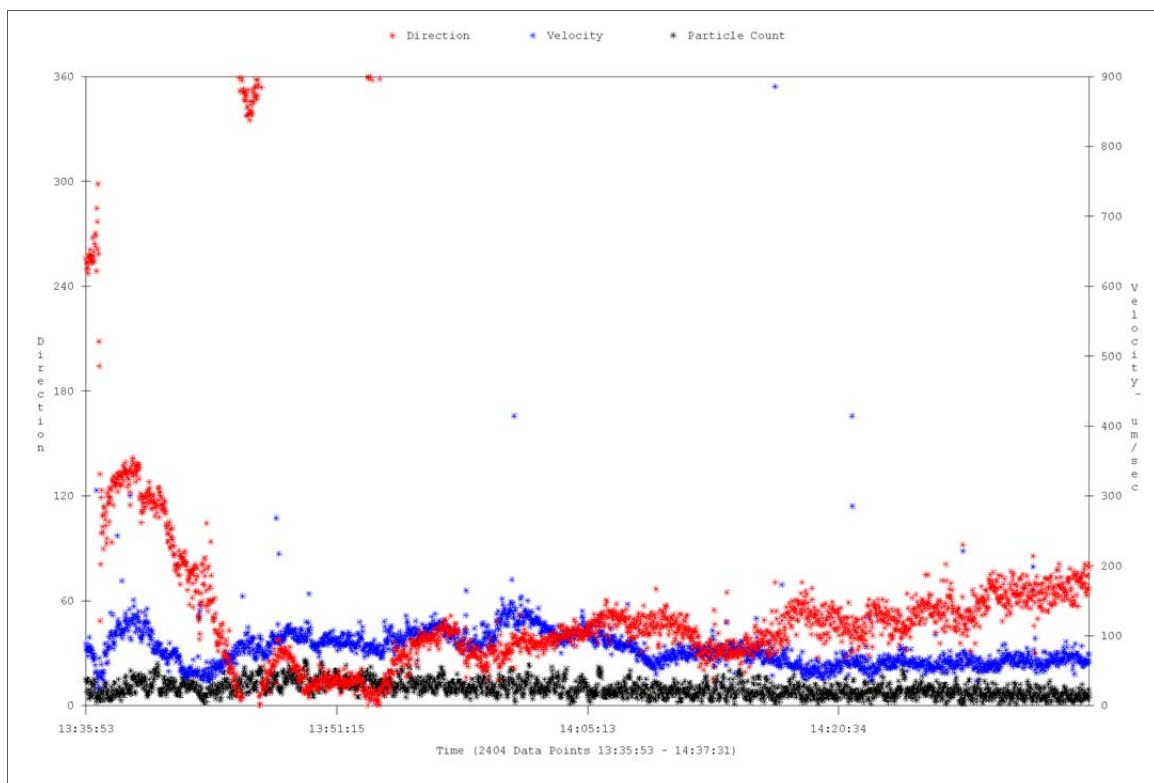
Colog measured horizontal water velocity, direction, and particle size with the 1 3/4 inch AquaVision Colloidal Borescope Flowmeter System (CBFM). Using a downhole video microscope with a 2.7 Millimeter (mm) x 2.0 mm field of view, the CBFM yields thousands of data points per minute for statistically assured data. Particulates within the fluid are tracked with the AquaVision software, assessing the velocity of each particle, and assigning a direction based on the on-board magneto resistive digital compass. Horizontal flow can be measured to depths up to 1000 feet.



Screen shot of the Colloidal Borescope showing particles and particle tracking in real time. System with the standard 200 foot cable reel. The optional 1000 foot cable was utilized in 517 Shaft.



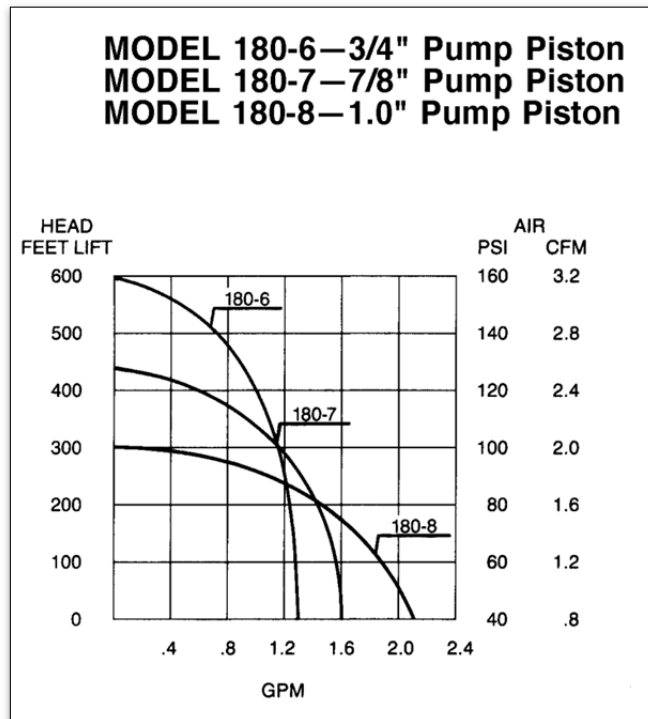
CBFM system set at a discrete testing location.



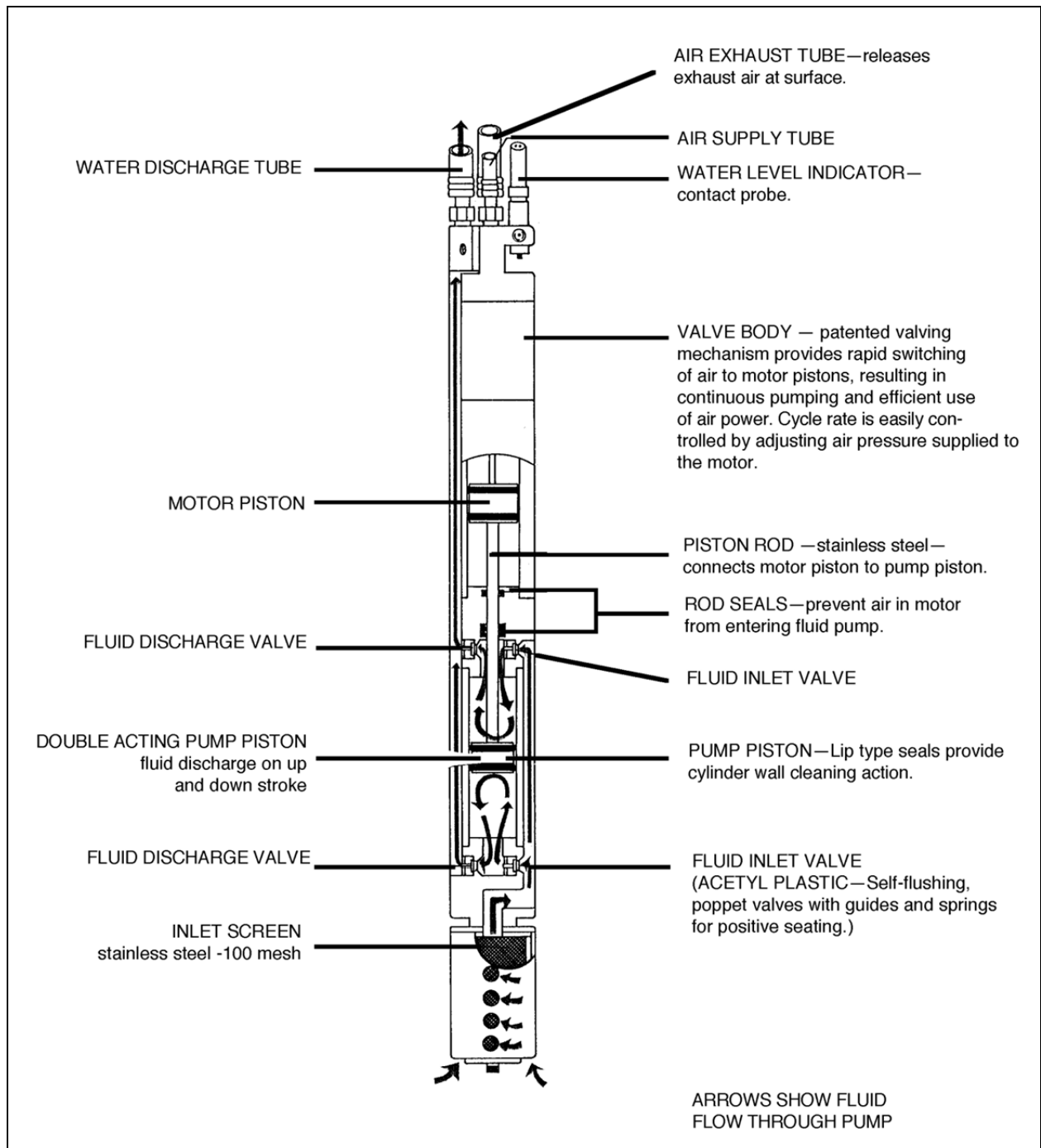
2,404 data points collected at an example testing location. The average direction (red) and velocity (blue) are calculated to provide statistically defensible values for this depth.

### E. Bennett Sample Pump

For fluid sampling at depth, Colog utilized the Bennett, model 180-6, air-driven, sample pump. The stainless steel pump has an automatic reciprocating piston motor, operated by compressed air that generates power for actuating a double-acting piston fluid pump. The ratio between the motor piston and the pump piston provides for significant lifts using relatively low pressure air from a small portable compressor. The pump discharge rate is controlled with an air pressure regulator. Exhaust air was vented into the fluid column. Prior to sampling at each station, five gallons of water were extracted from the station, approximately two tubing volumes, in order to purge the system of fluid from the previous station.



The 3/4" pump piston allows 0.4 GPM lifts from as deep as 500 feet, utilizing a 150 pound per square inch (PSI), 3 cubic feet per minute (CFM) compressor. Higher flow rates may be achieved in lower head environments. Lower flow rates are controlled by reducing air pressure.



Bennett sample pump configured for submerged operation.

## F. Profiling Sonar

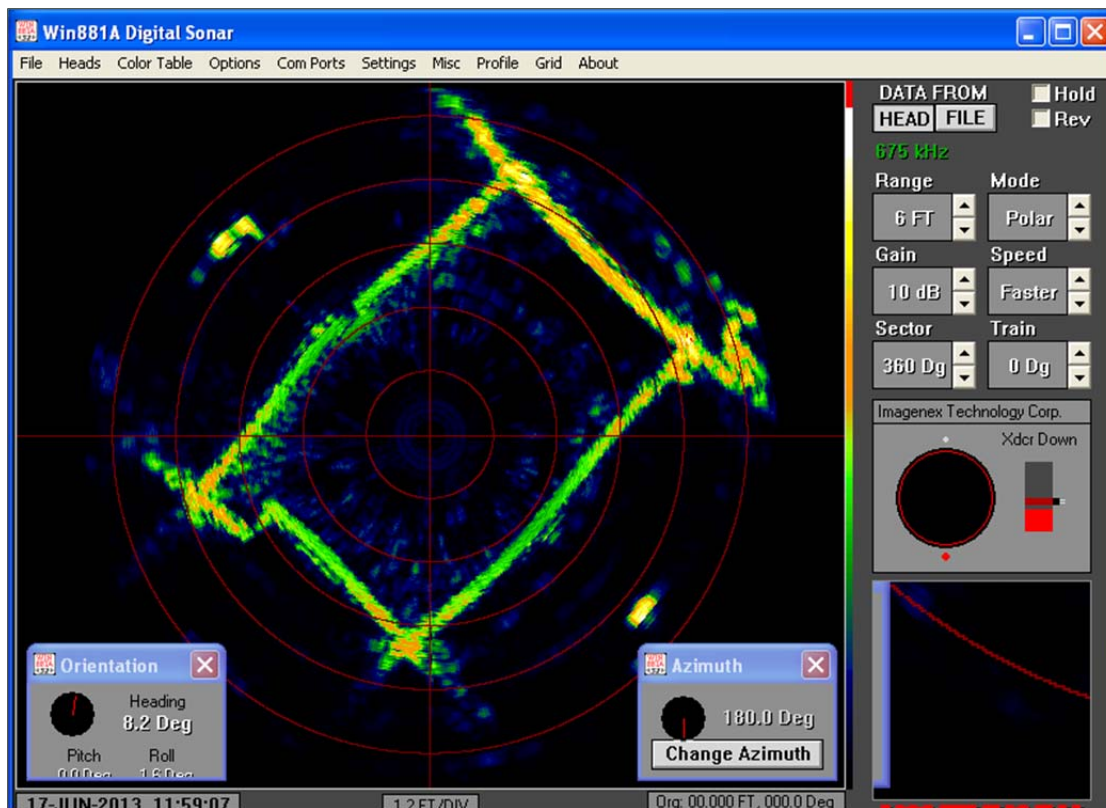
Multi-frequency profiling sonar surveys provide a unique means of imaging large, fluid-filled caverns and voids. Colog utilized the Imagenex Sonar Model 881A (sonar head) and adapted to a 4 conductor geophysical wireline.



The profiling sonar head is real-time configured through software, allowing a wide range of frequency selections and range resolutions. The user has the ability to fine-tune the profiling configurations and adjust to customize for different field applications.

- Frequency: tunable from 600 kHz to 1 MHz in 5 kHz steps
- Transducer: Fluid compensated profiling type
- Beam Width:
  - 600 kHz , 2.4°
  - 675 kHz, 2.1°
  - 1 MHz 1.4°
- Range Resolution:
  - 1 to 4 meters, 2mm (0.8")
  - 5 meters and greater, 10mm (0.4")
- Range Scales: 1m, 2m, 3m, 4m, 5m, 10m, 20m, 40m, 50m, 60m, 80m, 100m
- Horizontal Resolution:
  - 1200 samples per revolution (SPR), 0.3° increments
  - 600 SPR, 0.6°
  - 400 SPR, 0.9°
  - 300 SPR, 1.2°
  - 150 samples per revolution, 2.4 degree increments
- Vertical Resolution: Dependant on void dimensions and beam width

Two sets of data were collected, first at stationary intervals, or as a continuous profile while the sonar head was lowered into the 517 Shaft, and then continuously as the sonar head was extracted out of the mine shaft. The continuous extraction rate was 0.5 foot per minute.



Screen capture of the sonar field data acquisition software – Win881A.exe.

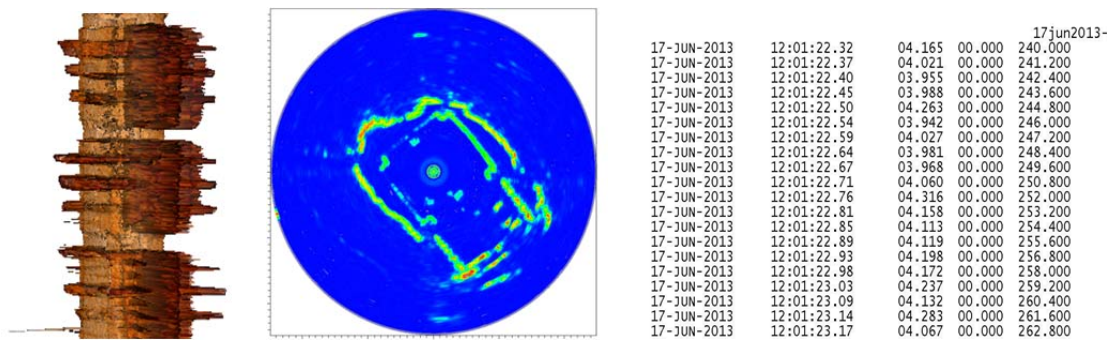
This image is from the 517 Shaft at 451.0 feet below the top of the shaft.

The sonar head face is at the top of the image and is heading 8.2 degrees east of magnetic north.

Each division represents 1.2 feet from the center of the sonar head.

Sonar images are oriented by a 3-Axis Magnetometer and 3-Axis Accelerometer. Heading, Pitch, and Roll are displayed in the acquisition screen. These data are integrated into the binary data stream for post processing and image presentation.

In-house processing software (SonarSHED™) has been developed in order to create a platform to accommodate the 2- and 3-dimensional acoustical displays and virtual images. Data are processed and displayed in different views and color scale enhancements using Software VisIT™ provided by Lawrence Livermore National Laboratory.



Representative data from the 517 Shaft, in various stages of post-processing.

After sonar images from the 517 Shaft were post-processed, they were imported into WellCAD™ to compare with the other geophysical logs in order to compile a concise summary of all data.

### **G. Downhole Video Survey**

Colog provided a downhole video survey utilizing a system manufactured by Aries Industries Company. The BT9601 dual view downhole inspection camera contains an articulating side view with 360 degree rotation. The complete stand-alone system utilizes a BT12713 camera control box and is integrated with a ¼" diameter, coaxial, steel-armored, 1500 foot wireline, on a motorized winch.

Video surveys were recorded on HD/DVD format and viewed in real time as the color camera was lowered downward. As objects were observed the camera functionality allowed for still frame focusing, sideward viewing, rotation of side image, and light intensity adjustments.

The video image was limited by the capacity for artificial light illumination and by poor water clarity.

### **III. Initial Interpretation**

The fluid characterization probes were able to provide some information about the state of the water within the mine shaft. The flow measurements were only nominally quantifiable, as the water was not forced through the small inner diameter of the CDFM, but instead flowed past the CDFM within the large shaft cross-section. For rough estimate, the flow velocity (feet per minute) through the CDFM was assumed to match the flow velocity through the entire mine shaft, and the cross-section was assumed to be a constant seven feet by seven feet. However, we know the cross-section varies as the configuration of the timbers, stairs, and adjoining tunnels vary. The flow measurements do, however, demonstrate trends of flow direction and relative magnitude. Changes in flow direction and magnitude are indicative of inflow or outflow and are generally supported by anomalies in the fluid quality logs (Attachment A).

The CDFM data indicated downward flow at depths of 453 and 454 feet, the surface of the submerged portion of the mine shaft.<sup>2</sup> Below the near-surface water level, all measurements indicated upward flow. This evidence suggests that, at about 454.5 feet, most of the water exits the mine shaft. Variations in the upward flow velocity indicate inflows and outflows but should be considered with the knowledge that the shaft cross-sectional area is not truly constant. Water was found to flow up, from 522.5 feet (the deepest point accessed by the CDFM) to 507.5 feet at a relatively constant rate. The velocity decreased slightly for the 502.5 foot station, suggesting a relatively low outflow between these stations. This depth corresponded with an apparent void, indicated by the sonar survey; very little acoustic energy was returned to the sonar head at this depth. Similarly, a drop in the upward flow rate between the 497.5 foot and 492.5 foot stations suggested another outflow. The upward flow rate increased incrementally from 487.5 feet up to 472.5 feet, suggesting a source of inflow to the mine shaft. Substantial drops in the upward flow rates at 467.5 and 466 feet suggested some outflow in this region. Upward flow was variable up

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<sup>2</sup> Raw depth measurements varied somewhat by instrument and were corrected to the water surface depth during post-processing.

to 455 feet, but within a narrow range, not showing strong evidence for much inflow or outflow until about 454.5 feet.

At the depths where the CDFM suggested inflow or outflow, the CBFM was stationed to assess horizontal flow magnitude and direction. Directions are indicated on Attachment A, by the direction of the tadpole tail (north is up; azimuth values increase in a clockwise direction). Magnitudes are also notated on the plot. Horizontal flow was consistently measured toward the north to northeast, with a maximum velocity of 65.53 feet per day at 468.5 feet.

Additional depths were selected for fluid sampling. At each depth, after purging the sample line with multiple tubing volumes, samples were extracted from the mine shaft, with the Bennett sampling pump, and collected at the surface. These samples were submitted by AMEC to Pace Analytical Laboratories for analysis of total and dissolved metals and ions. Those data will be presented under separate cover. Water quality parameters, measured using a calibrated YSI 556 multi-probe system, connected to the sample tubing via a flow-through cell, are presented in the following table and are indicated on Attachment A.

Location ID	Date	Time	Depth Below Shaft Collar	Sample ID	Purged Volume (L)	Temp. <sup>1</sup> (°C)	SEC <sup>1</sup> (uS/cm)	DO <sup>1</sup> (mg/L)	pH <sup>1</sup> (su)	ORP <sup>1</sup> (mV)	Comments
517 Shaft	05/16/2013	12:10	463	517Shaft463130516	10.1	10.08	1,588	5.34	6.87	173.4	Clear
	05/16/2013	12:50	475	517Shaft475130516	19.7	10.20	1,598	5.51	6.90	171.2	Clear, some particulate matter
	05/17/2013	11:46	500	517Shaft500130517	36.0	12.04	1,595	5.57	6.90	184.2	Clear, some particulate matter
	05/17/2013	12:08	502	not sampled	14.0	12.33	1,596	5.51	6.94	178.0	Particulate matter
	05/17/2013	12:27	504	not sampled	17.8	12.36	1,595	5.92	6.96	178.7	Particulate matter
	05/17/2013	12:42	506	not sampled	15.8	12.75	1,595	6.01	6.98	182.2	Particulate matter
	05/17/2013	13:01	508	not sampled	19.0	12.87	1,596	6.22	6.97	181.4	Yellowish particulate matter in water
	05/17/2013	13:16	510	not sampled	16.6	13.07	1,595	6.48	6.99	182.3	Yellowish particulate matter in water
	05/17/2013	13:36	515	not sampled	18.8	13.20	1,597	6.62	6.91	186.7	Yellowish particulate matter in water
	05/17/2013	13:55	520	517Shaft520130517	18.4	13.15	1,597	6.72	6.97	192.4	Yellow-orange water, floating particulate matter
<b>Notes:</b>											
1. Field water quality parameters measured with a calibrated YSI 556 multi-probe system.											
<b>Abbreviations:</b>											
°C = degree Celsius			ORP = oxidation reduction potential								
DO = dissolved oxygen			SEC = specific electrical conductance								
L = liter			su = standard unit								
mg/L = milligram per liter			uS/cm = microsiemen per centimeter								
mV = millivolt											

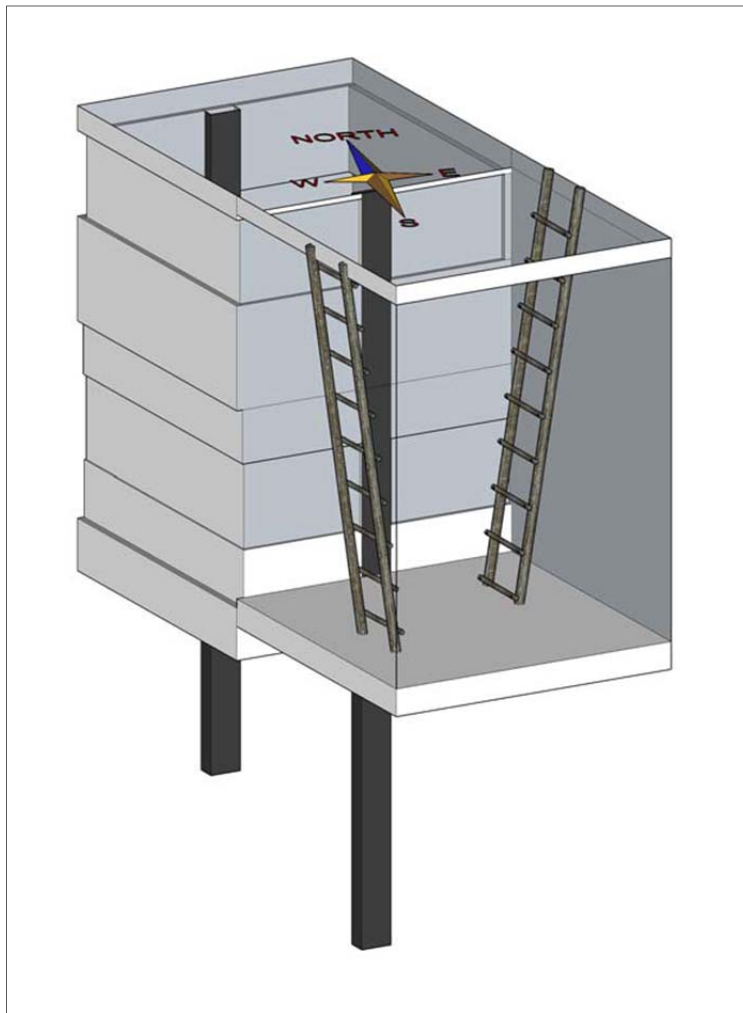
Sonar mapping indicated, in general, a shaft condition and shape consistent with what was observed in the video above fluid level.<sup>3</sup> A main shaft, constructed of vertical timbers, bound by a square frame of horizontal timbers, with vertical spacing of about one foot between each timber. Lift guides are observed in the center of the southeast and northwest sides. From the water surface to a depth 492 feet, sonar mapping indicated a secondary shaft outside the main shaft, on the southeast side. This secondary shaft was of similar size to the main shaft and divided into sections approximately seven feet tall, with a one foot separation between each section. The presence of the secondary shaft was consistent with the ladder access shaft observed above the

<sup>3</sup> Fluid level was established as 453.4 feet below the top of the mine shaft.

water level, in the video inspection. The secondary shaft was not apparent below 494 feet, but the lift guides remained.

Below 494 feet, the timber pattern appeared to be more consistent rather than layered. Large voids absorbed most of the acoustic signal from 503 to 506 feet, at 524 feet, from 525 to 527 feet, and below 536 feet. The most pronounced constriction was observed at 523 feet on the northeast side of the main shaft.

Attachment C presents the first set of sonar plots at a depth scale matching the other geophysical logs (Attachment A). The second plot (Attachment D) has an expanded scale to show detail. In each presentation, the column title indicates which side of the 517 Shaft is being observed, from the outside, if the shaft were a solid body. The following is a rendition of the basic shaft arrangement, based on observations from the video and sonar surveys.



Rendition of a length of the 517 Shaft, as imaged by the video and sonar inspections.



**ATTACHMENT A**  
**Geophysical Summary Plot**



Geophysical Summary Plot

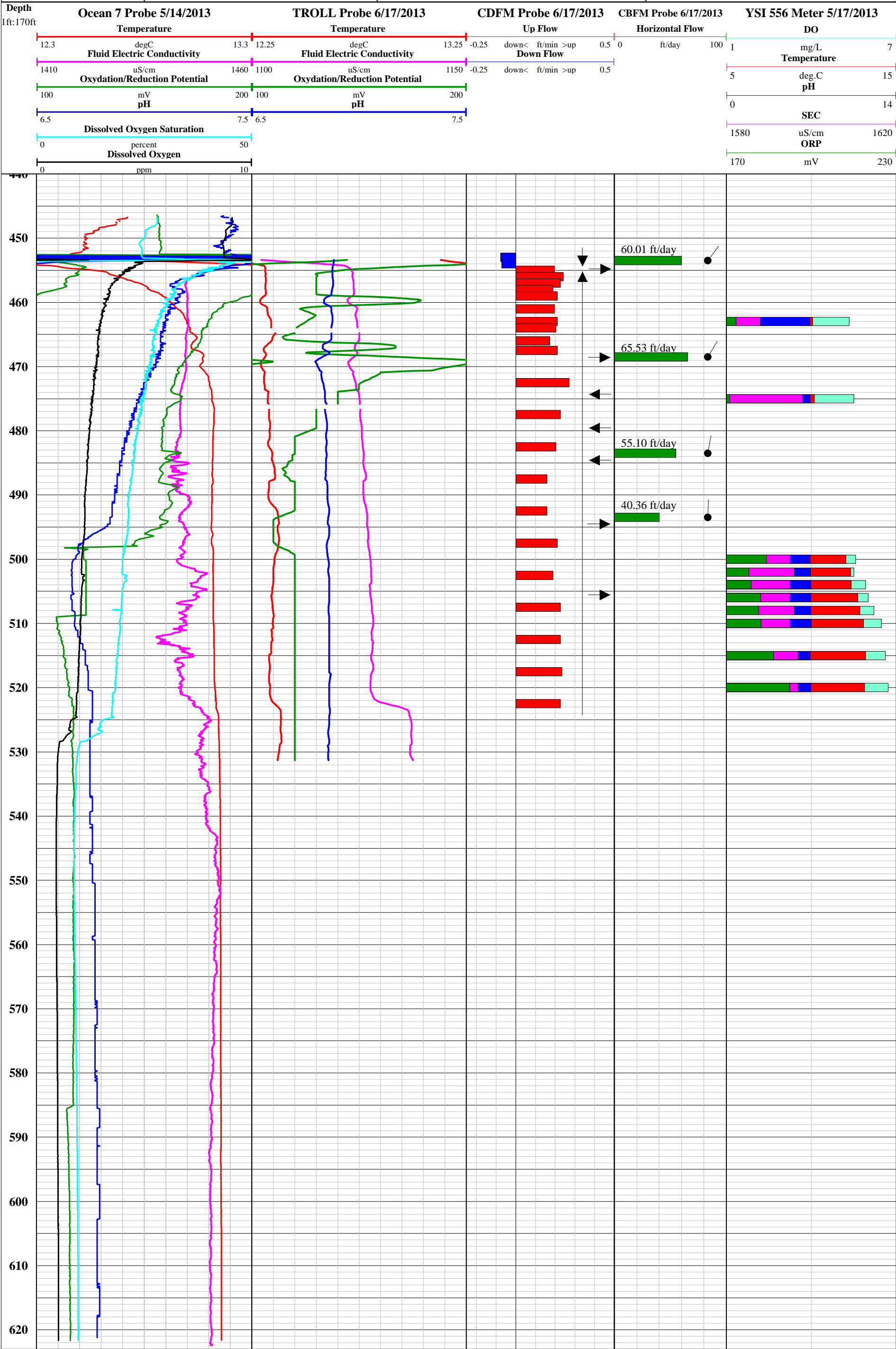
COMPANY: AMEC

PROJECT: Rico-Argentine Mine

DATE LOGGED: 5/14, 6/17 2013

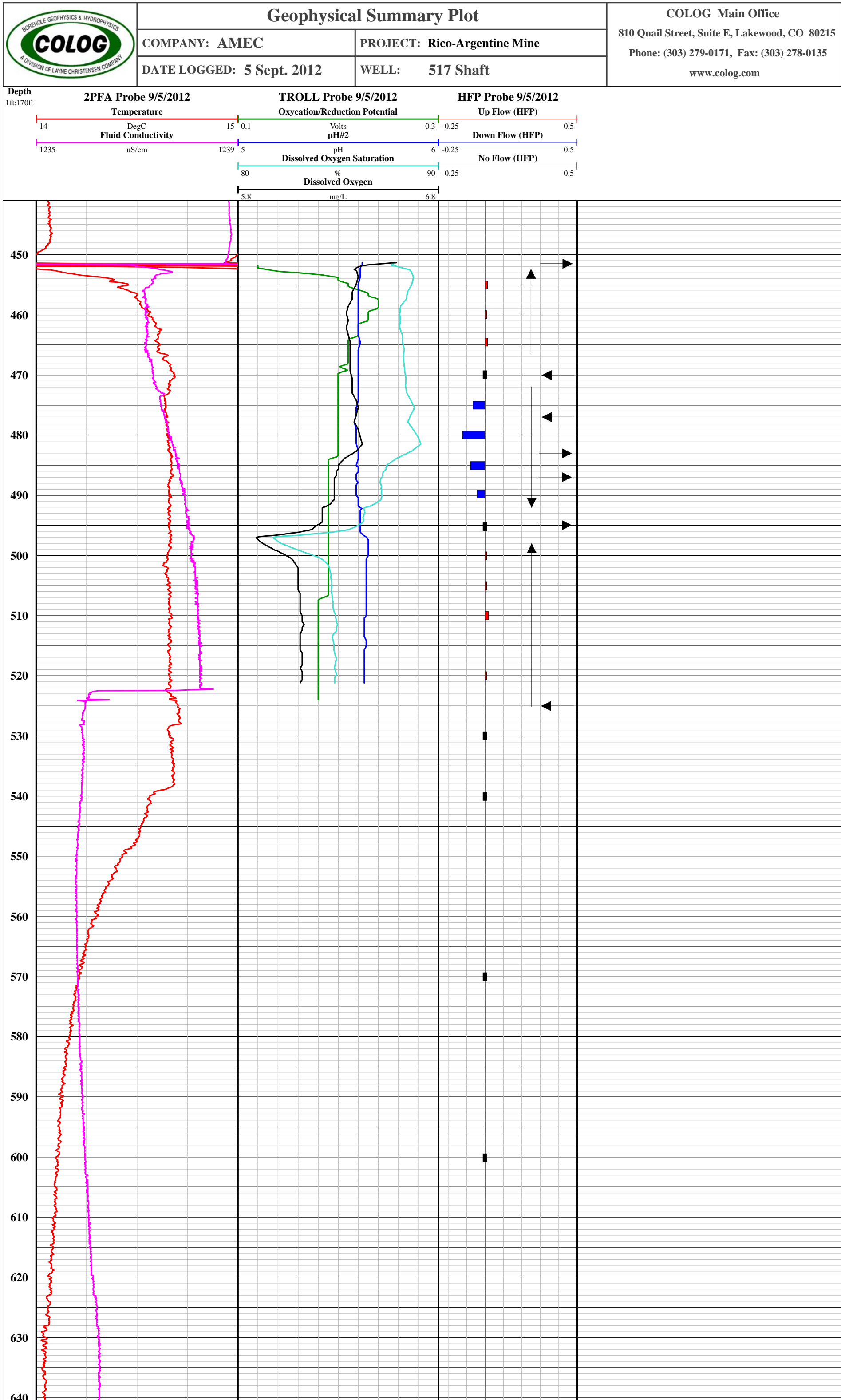
WELL: 517 Shaft

COLOG Main Office  
810 Quail Street, Suite E, Lakewood, CO 80215  
Phone: (303) 279-0171, Fax: (303) 278-0135  
www.colog.com



**ATTACHMENT B**

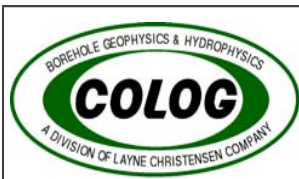
**Geophysical Summary Plot – September 2012**



**ATTACHMENT C**

**Sonar Summary Plot – 1 foot:170 feet**





## Sonar Summary Plot

COMPANY: AMEC

PROJECT: Rico-Argentine Mine

DATE LOGGED: 18 June 2013

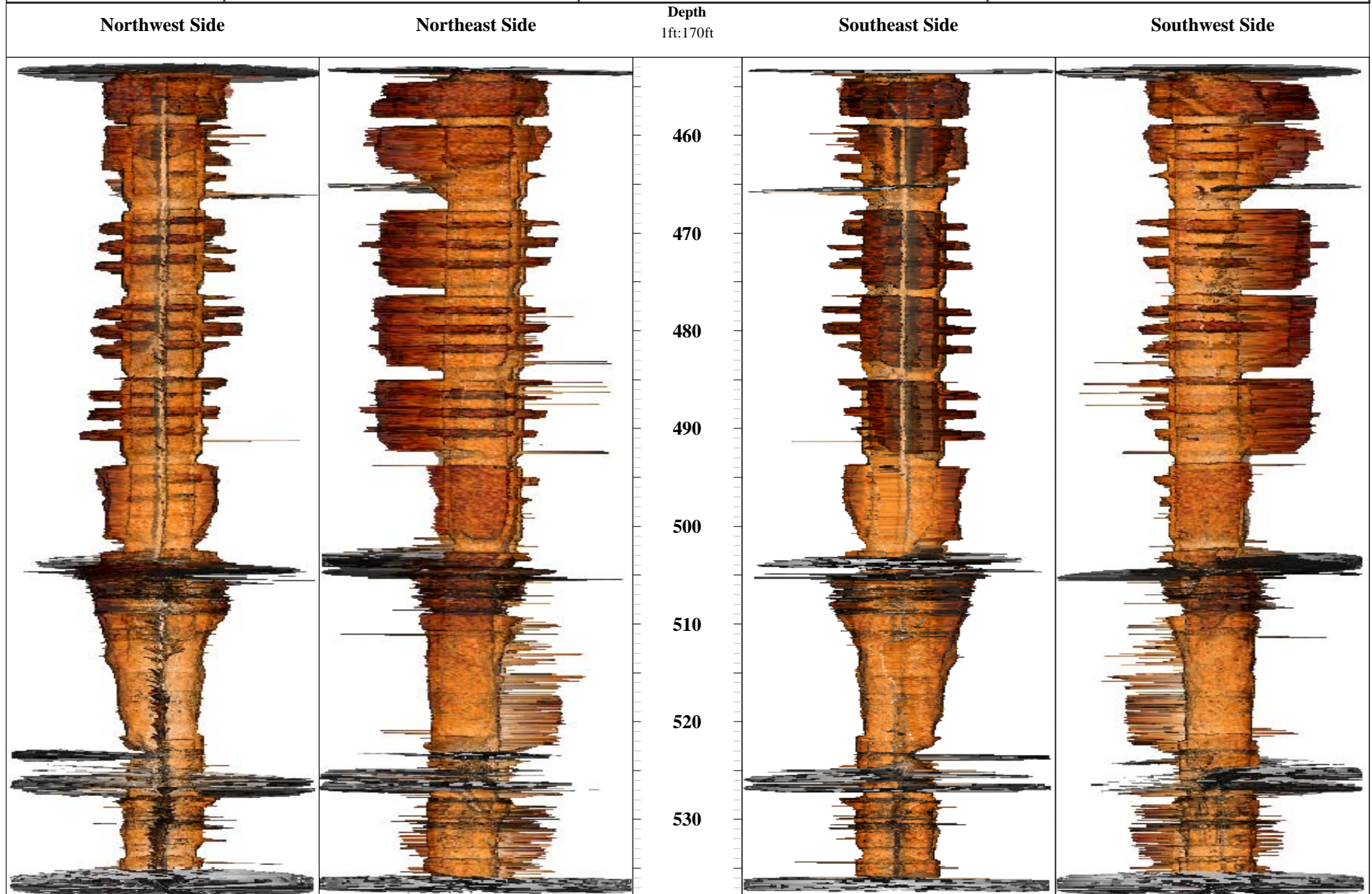
WELL: 517 Shaft

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810 Quail Street, Suite E, Lakewood, CO 80215

Phone: (303) 279-0171, Fax: (303) 278-0135

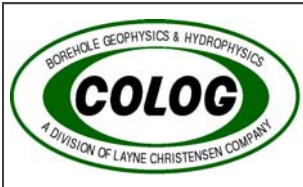
[www.colog.com](http://www.colog.com)



**ATTACHMENT D**

**Sonar Summary Plot – 1 foot:70 feet**





Sonar Summary Plot	
COMPANY: AMEC	PROJECT: Rico-Argentine Mine
DATE LOGGED: 18 June 2013	WELL: 517 Shaft

COLOG Main Office
810 Quail Street, Suite E, Lakewood, CO 80215
Phone: (303) 279-0171, Fax: (303) 278-0135
www.colog.com



Insert DVD of the 2013 downhole  
video with hard copies.

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**ATTACHMENT 5-2**

517 Shaft Geophysical Characterization A-Frame Structure and Wireline



**517 SHAFT GEOPHYSICAL CHARACTERIZATION  
EVALUATION OF SOURCE WATER CONTROLS  
Rico-Argentine Mine Site  
Dolores County, Colorado**



Wireline attached to the A-Frame structure above the 517 Shaft collar during 2013 geophysical characterization work.